PHYSIOGRAPHY

FOR ADVANCED STUDENTS

A. T. SIMMONS

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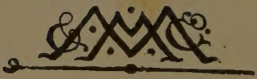

PHYSIOGRAPHY
FOR ADVANCED STUDENTS

BY

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PREFACE

THE course of elementary physiography, outlined in the helpful syllabus issued by the Department of Science and Art in 1896, constitutes an excellent introduction to physical science. In the advanced stage of the subject, the fundamental principles described in the elementary course are developed and expanded so that the two stages together provide the student with a comprehensive view of various branches of natural knowledge.

A little book, entitled *Physiography for Beginners*, designed to assist students taking up the elementary stage of the subject, has met with so favourable a reception that the author has been encouraged to prepare a volume to cover the advanced course. The present book is the result.

The plan which was adopted in the earlier part of supplying precise instructions for simple experiments to exemplify the principles underlying the phenomena described, has been adhered to, as well as that of briefly summarising the chapters and adding questions (some of them from examination papers in physiography) for home exercises, when the book is used in classes.

A glance through the pages will, it is believed, afford justification for the hope that the general reader who is anxious to become acquainted with the causes of familiar natural phenomena, such as cyclones, tides, seismic disturbances, &c., will find the volume serviceable and interesting. It must be understood, however, that an acquaintance with the principles explained in the book to which this one is a supplement, is necessary before clear ideas can be obtained with regard to the facts herein described.

Two distinctive features of the present book are the large number of illustrations and the frequent references to original papers upon various branches of physiography. For both these characteristics the author is very largely indebted to Mr. R. A. Gregory, who has not only lent him numerous papers from the *Proceedings* of scientific societies and referred him to many others, but has also placed at his disposal a large collection of illustrations which have never before appeared in a work on physiography.

The opportunity of thanking Mr. Gregory for these services, as well as for his invaluable assistance, especially in the astronomical chapters, is gratefully accepted by the author, who is deeply conscious of his great indebtedness to this well-known writer on the subject.

The author's thanks are also due to the publishers for permission to use illustrations from books dealing with various branches of physiography. Specific acknowledgment of the sources of these illustrations will in most cases be found at the end of the inscriptions under them.

A. T. SIMMONS.

November, 1897.

Lantern slides of any of the illustrations in this book may be obtained through the publishers, Messrs. Macmillan and Co., Ltd.; price 1*s*. each.

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CHAPTER I

MATTER

Introductory.—The student has, we must assume, become familiar in an elementary course with the meaning assigned to the word matter. He has learnt that it must occupy space or possess *extension*; that two portions of matter cannot occupy the same space at the same time, a fact we express by saying that matter is *impenetrable;* that matter offers resistance, possesses weight, and can impart motion to other portions of matter when it strikes against them.

To be quite correct, it is necessary to state that impenetrability is really not a property of matter in the lump, but only of those ultimate divisions of matter which are referred to under the name of *molecules*. Molecules alone are impenetrable. The volume occupied by any material thing is made up of that of its molecules plus that of the interstices. When a material body is compressed the molecules are brought closer together by a diminution in the total volume of its interstices. This explains, too, the common experiment[1] of adding a known volume of alcohol to a known volume of water, and noticing, after shaking them together, that the resultant volume is less than the sum of the volumes of the constituents. We must, to explain this phenomenon, suppose that some of the molecules of alcohol take up their position in the interstices of the water and *vice versa.*

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[1] *Physiography for Beginners.* Expt. 2.

It should also have been learnt that matter often possesses all or some of the following properties, namely, Divisibility, Porosity, Compressibility, Elasticity, and Inertia—as well as what is meant, in a general way, by each of these terms. We shall have, in this chapter, to inquire more closely into the phenomena associated with some of these properties, and also to learn that the simple division of material things into gases, liquids, and solids is not a sufficiently accurate expression of what is known on the subject.

The States of Matter.—There is no hard and fast line dividing one state of matter from another. There is a gradual transition from that ideal form of matter—a perfect solid—through several stages to a gas, and on to what is known as *radiant matter.* A distinction must be made between mobile and viscous liquids, and we must think of sealing-wax not as a solid but as a very viscous liquid because of the power of flowing which it has been seen to possess.[1] However soft a material thing may be, yet if it has no power of flowing, it must be regarded as a solid. Thus jelly is a solid because it will not flow, a fact which can be demonstrated by placing a very small weight, such as a mustard seed, upon it; the slight depression which the seed causes does not increase with the lapse of time, hence there is no flow, or the jelly possesses a certain small amount of *rigidity.*

Solids.—Rigidity.—This possession of rigidity constitutes a means of distinguishing between a solid and a liquid, and we shall do well to consider more fully what is meant by the property. Imagine a material substance, for the sake of simplicity suppose it in the form of a wire, acted upon by a stress,[2] brought about, for instance, by the action of a stretching weight. If the wire experienced a definite elongation which did not increase with the lapse of time, or, what is the same thing, which remained constant for the same stretching weight, it would be a *perfect solid.* Ordinary wires, such as those of iron or copper, appear to exhibit this behaviour when only approximate measurements are made, but if the measurements are accurate enough it is found that the elongation is subject to a very slight and gradual increase. The ratio of the deformation, in our example the amount of stretching, to the deforming force, which is here the stretching weight, is in a perfect solid always the same—or, as is more commonly said, it is *constant*. This can be expressed differently—the material body under consideration is in a state of stress, while the deformation is known as a *strain*, so that we can write for a perfect solid

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[1] *Physiography for Beginners*, p. 6.

[2] *Ibid.*, p. 38.

$$\frac{\text{strain}}{\text{stress}} = \text{a constant.}$$

If the value of this fraction were 0 and remained so, such a solid would be absolutely rigid ; in those solids where its value is very small, or where the deformation produced is exceedingly small compared with the amount of the deforming force we have a very high degree of rigidity. In other words, if the reciprocal of the above fraction, *i.e.*—stress divided by strain—which is known as the *co-efficient of rigidity*, is very high, the solid is spoken of as rigid. Whereas if the co-efficient of rigidity is very small the solid is said to be *soft*. Hence in soft solids a small deforming force, or a slight stress, produces a considerable strain, as with the jelly described.

Fluids.—Referring to the above equation, in the case of those material bodies where the value of the fraction is not constant, but increases with the lapse of time, the term *fluid* is used. Since, as was noticed by Maxwell and as has already been mentioned, the value of the fraction in the case of metal wires increases slightly with an increase in the length of the duration of the action of the deforming force, it is evident that to this small extent the metal possesses fluidity. But the resistance to their flow, or their viscosity, is very high. Soft solids are generally less viscous, though in some bodies ordinarily thought of as solids the degree of fluidity is very considerable. The behaviour of sealing-wax and pitch has already been studied by the student. With these substances the value of the expression —strain divided by stress—does increase with the lapse of time, though only slowly. They are very viscous fluids. As the amount of viscosity diminishes, the fluids become more and more mobile. As far as we have gone, therefore, we have traced a gradual passage, by imperceptible steps, from an ideal perfect solid to rigid solids, soft solids, viscous liquids, until we have reached mobile liquids.

Vapours.—Suppose that a quantity of an ordinary mobile liquid, such as water, is contained in a suitable vessel, which it does not fill, and that all air is removed from the space above the liquid, and the vessel closed : there will be nothing but the water in the vessel, and its surface will be clearly marked. But from what the student knows of evaporation he will perceive that a certain definite quantity (depending upon the temperature) of the water will become converted into a gas which will fill the space above the liquid, and exert a pressure upon the sides of the containing vessel. If the temperature is raised the amount volatilised will be increased and the internal pressure will become greater. If the temperature is lowered, some of the gas above the water will be condensed again into a liquid. Gases of this order, which by a diminution of temperature are easily converted into liquids, are known as *vapours*. A distinction between what are called *saturated* vapours and those known as *unsaturated* is drawn. The former are those which only a slight amount of cooling will liquefy, while the latter may undergo some considerable cooling without experiencing condensation. It must also be pointed out that under some circumstances this condensation can also be brought about by an increase of the external pressure.

The Critical Condition.—There is a point in the passage of matter from the gaseous to the liquid condition at which it is impossible to say whether the substance is a gas or a liquid. Cagniard de la Tour observed in 1822,[1] by heating some liquids in glass tubes which they almost filled, that when a certain temperature was reached, the substance, "which till then was partly liquid and partly gaseous, suddenly became uniform in appearance throughout." There was no line of demarcation to be distinguished. His explanation that the whole of the substance at this particular temperature was converted into a gas was erroneous, as we shall see. Dr. Andrews explained the actual condition of things by researches on carbon dioxide in 1869.[2] He found "that the gaseous and liquid states are only widely separated forms of the same condition of matter, and may be made to pass one into the other without any interruption or breach of continuity." Dr. Andrews found in the case of carbon dioxide that at 31° C., if the gas be subjected to a pressure of 73 atmospheres, the gaseous merges into the liquid condition. No pressure, however high, will liquefy gaseous carbon dioxide when it is at a temperature above 31° C. But if, while under the influence of a pressure greater than 73 atmospheres, it is cooled below 31° C. it becomes a liquid—though the passage from one condition to the other cannot be observed. This temperature of 31° C. for carbon dioxide is known as its critical temperature.

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[1] *Annales de Chimie*, 2me serie, XXI. et XXII.

[2] *Philosophical Transactions*, 1869, p. 575.

Gases.—There is a critical temperature for every gas. In the case of what used to be called the permanent gases—oxygen, hydrogen, &c.—the critical temperature is very low indeed, that of oxygen being – 113° C., and, consequently, it is only at a very low temperature that the action of even a great pressure will cause their condensation. These considerations afford us another means of distinguishing between a vapour and a gas. Since no pressure is sufficient to liquefy a gas which is at a temperature higher than the critical temperature, it is manifest that it is not, under these circumstances, a vapour; while, since it is easily liquefied when cooled below its critical temperature, it is then a vapour. Or, *vapours are gases below their critical temperatures.*

Radiant Matter.—Experiments made with air and other gases at an extremely low pressure, such as exists in the so-called "vacuum" tubes with which every reader will doubtless be familiar, tend to show that highly rarefied gases behave in a peculiar manner. If an electric discharge from an induction coil or an electrical machine is sent through a gas in this highly rarefied condition it glows with a very bright light. When the amount of gas in the tube is very minute, or, what is the same thing, if the "vacuum is good," and the tube is very narrow, the passage of the electric flash causes the glow produced to break up into layers of a most beautiful kind, Fig. 1, which flicker considerably as the intensity of the discharge varies. When the pressure in the tube has been diminished to an amount about one-millionth of the atmospheric pressure, the highly rarefied matter still present becomes radiant. Strange and unusual phenomena are observed. The molecules of gas which come in contact with the negative pole are repelled in a direction at right angles to the surface of the pole. The impact of such molecules with one another causes an internal glow. Their contact with the glass causes it to become phosphorescent and any part of the glass protected from this bombardment remains dull (Fig. 2). Should they strike a movable body they produce a mechanical effect. This can be shown by a small light paddle wheel arranged in an exhausted glass tube as in Fig. 3. The wheel runs from one end of the tube to the other when the radiant molecules from the negative electrode strikes upon its upper vanes. There is as wide a divergence between the behaviour of the highly rarefied gas in these tubes and a gas under ordinary conditions of pressure as there is between such a gas and a liquid.

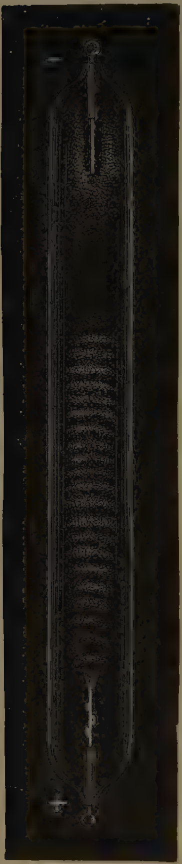

FIG. 1.—Stratified Electric Discharge in a Vacuum Tube.

Properties of Matter.—It will now be necessary to carry what has been said about the general properties of matter in the elementary stage of the subject a little further; and we shall do this by considering in order the subjects of *compression*, *elasticity*, and *torsion*.

Compression and Extensibility.—These properties follow the same rules, and hence we can deal with them together in a very large measure. Some substances if acted upon by a stretching stress become greatly elongated, while others experience very little such extension.

Clay affords an instance of the latter bodies, while india-rubber can be cited as a good example of the former. If a piece of india-rubber tubing is stretched by a weight,[1] and if we measure the amount of elongation produced in the length of tubing, and divide the increase of length by the original length, we shall have measured the extension produced.

---

[1] *Physiography for Beginners*, p. 6.

$$\frac{\text{increase in length}}{\text{original length}} = \text{extension.}$$

The *extensibility* of the india-rubber is found by dividing the extension obtained by the stretching weight. Or the extensibility is the ratio between the extension produced and the extending force.

$$\frac{\text{extension}}{\text{extending force}} = \text{extensibility.}$$

Extension of solids cannot go on indefinitely. As the weight with which the wire, rod, cord, or whatever form of the material body is used, is increased, a point is gradually reached at which the cohesion of the substance is exceeded, and the body is broken. The weight which for a given wire just causes breaking is spoken of as the *breaking weight*, and is evidently a measure of the body's *cohesion*. Bodies are compressed by the application of external pressure. The compression is measured by the ratio of the decrease in volume produced to the original volume of the body; while as before the compressibility is the ratio of the compression to the compressing force. As excessive exten-

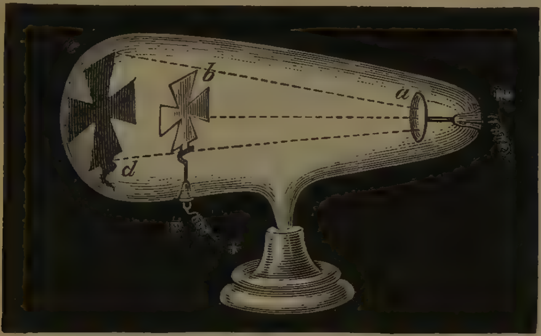

FIG. 2.—Showing Radiant Matter projected from the Negative Pole (a) of a high-Vacuum Tube, and the result of protecting a part of the glass from Molecular Bombardment by means of the screen b.

sion causes breaking, so excessive compression results in *crushing*, the pressure which just causes crushing being referred to as the *crushing pressure.*

It is of the highest importance to engineers that they should have accurate knowledge of these co-efficients for all the materials they use in their work, and very accurate mechanisms have been designed for determining the strength of materials, but the interested student should read books devoted to this subject.[1]

Elasticity.—Elasticity is regarded as a tendency to go back to the original form or volume after being forced out of it and it can be developed in solids in at least four ways, by pressure, by pulling, by bending, and by twisting. The elasticity called into play by pressure is, however, common to all forms of matter, while it will be sufficient for our purpose to regard the other three as specific properties of solids.

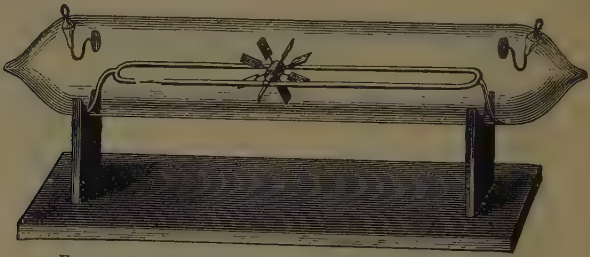

FIG. 3.—Mechanical Effect produced by Radiant Matter.

In the case of an elastic body undergoing compression, another force is called into existence which acts in opposition to that bringing about compression, and this force, known as that of *restitution*, is the result of the body's elasticity. It is the effort of the body in consequence of its elasticity to prevent compression. The ratio of the force of restitution to that of compression is spoken of as the *co-efficient of elasticity*. If this value were 0 the body would be *inelastic*; if it were 1 it would be perfectly *elastic*, but neither of these values are known for any form of matter. All observed values lie between these limits or all known substances are *imperfectly elastic*.

---

[1] Such as Anderson's *Strength of Materials.*

In order that a body might be perfectly elastic, it would have to possess the following properties[1]:—

1. It must offer a definite resistance to distortion.
2. The distortion is not permanent, and if the deforming pressure be removed, the distorted body springs back to its original form or bulk.
3. The distorting pressure must be continuously maintained in order to keep up the distortion.
4. As long as a distorting pressure is kept up, there is a counter pressure or restitution pressure developed and sustained in the elastic substance. As this holds the deforming pressure in check, and is in equilibrium with it, thus setting up a condition of stress in the substance, it must be numerically equal to it.
5. The restitution pressure does not become diminished by lapse of time.

Elasticity of Pulling.—Modulus of Elasticity.—

EXPT. I.—Hang a piece of india-rubber cord about 2 feet long to a support as in Fig. 4, and attach a scale pan to the free end. Thrust two pins through the india-rubber about 18 inches apart when the pan is empty. Add a weight of say 100 grams and observe the distance between the pins, either by means of a scale fixed to the support, or by direct measurement. Double the weight and again observe the elongation produced. Substitute a thicker piece of india-rubber cord for the first piece used, and repeat the experiment. It will be found that the elongation is different.

Careful experiments in which the measurements are very accurately performed by means of a cathetometer, which is a telescope moving up and down a carefully divided upright, have established the rule that the amount of elongation depends upon the following factors, viz.: the length of the wire, rod, or cord, the sectional area, the material, and the amount of the stretching force.

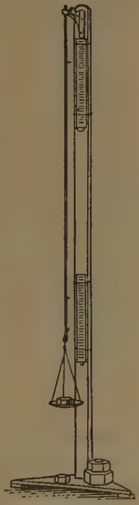

FIG. 4.—Experiment to illustrate the longitudinal stretching of an India-rubber Cord.

For a given wire of an original length l, stretched by a weight W until its length is l', it is found, provided that the wire is not stretched beyond its limit of perfect elasticity,

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[1] See Daniell's *Text Book of the Principles of Physics*, p. 264.

$$\frac{\text{length when stretched} - \text{original length}}{\text{original length} \times \text{stretching-weight}} = \text{constant}$$

$$\text{or } \frac{l' - l}{lW} = \text{constant}$$

That is the ratio of the extension (p. 7) to the extending force, or the extensibility is constant.

The amount of elongation, within the limits of elasticity, is directly proportional to the length of the wire, to the stretching weight, and to the *specific* elasticity of the material; but inversely proportional to the area of the cross section of the wire. If we call the specific elasticity E and the area of the section s, still using the letters above for the length and stretching weight, we can express the rule by an equation :—

$$\text{length when stretched} - \text{original length} = \frac{\text{specific elasticity} \times \text{original length} \times \text{stretching weight}}{\text{area of cross section}}$$

or expressed in symbols

$$l' - l = \frac{E \times l \times W}{s}$$

from which it is apparent that

$$\text{co-efficient of elasticity} = E = \frac{s(l' - l)}{lW}$$

E is known as the *coefficient of elasticity*, but its value is so small that it is usual to use its reciprocal, and to speak of this as the *modulus of elasticity*, that is to say

$$\text{modulus of elasticity} = \frac{1}{\text{co-efficient of elasticity}} = \frac{1}{E}$$

therefore

$$\text{modulus of elasticity} = \frac{\text{original length} \times \text{stretching weight}}{\text{area of cross section} \times (\text{length when stretched} - \text{original length})}$$

$$= \frac{lW}{s(l' - l)}$$

Elasticity of Bending.—When a solid in the form of a lath is bent by a weight on one end, the other being fixed,[1] it is evident that the matter beneath is subjected to compression, while that above undergoes extension, and that along some intermediate plane there is neither compression nor extension, the length of the rod being unaltered along this plane. If, however, the beam be supported at both ends and loaded in the middle, as in Fig. 5, the lower parts are extended and the upper portions compressed. In either of these examples there is a persistent tendency on the part of the lath to resume its original form, due to the elasticity of the material, and this force of restitution thus called into play persists as long as the bending force continues to be applied. The amount of bending in the case of a beam of rectangular section varies with its linear dimensions, the bending weight, and the modulus of elasticity.[1]

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[1] *Physiography for Beginners*, p. 7.

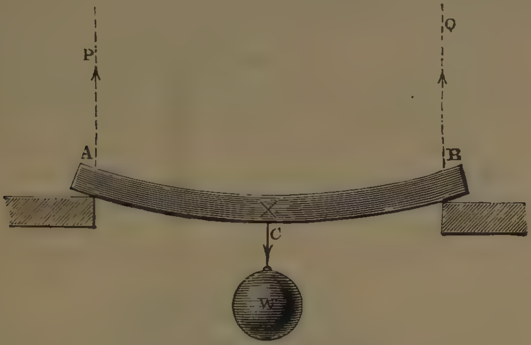

FIG. 5.—Beam supported at both Ends and Loaded in the Middle.

Elasticity of Twisting.—By means of the arrangement shown in Fig. 6, a wire can be twisted and the power to resist the torsion or twisting can be found by observing the rapidity with which the wire untwists.[2] If after twisting the wire by means of the weight, it is let go, the time which the wire takes to completely untwist itself can be observed. If ten or fifteen oscillations of this kind are observed, the time of a single oscillation can be more accurately determined than from a single oscillation. In this way ascertain (*a*) The time of one oscillation; also measure (*b*) the length of the wire and (*c*) the diameter of the wire. It will be found that if the oscillations are within a certain

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[1] If f = amount of bending, W = weight attached, $l, b, h,$ = length, breadth, and thickness of the beam, E = co-efficient of elasticity, then experiment shows that

$$f = E\frac{Wl^3}{bh^3}$$

[2] *Physiography for Beginners*, p. 7.

amplitude, that however they vary in amount, they are performed in very nearly equal times; that when the same twisting force is applied with wires of the same diameter, the angles of torsion measured by the angles moved over by the index, are directly proportional to the length of the wires. If the same twisting force is applied, that is, if the force of torsion is kept constant and the wires are kept of the same length, the angles of torsion are inversely proportional to the fourth powers of the diameters. Moreover, the angle of torsion is directly proportional to the force of torsion.

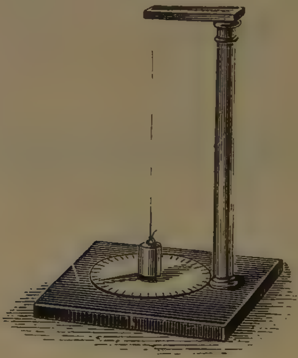

FIG. 6.—Elasticity of Twisting.

These rules can all be expressed by an equation. If α = the angle of torsion; F = moment of the force of torsion; l, r, = respectively the length and radius of the wire and $\frac{1}{T}$ = specific co-efficient of torsion, then

$$\alpha = \frac{1}{T} \times \frac{Fl}{r^4}$$

CHIEF POINTS OF CHAPTER I.

General Properties of Matter.—Every material thing possesses *impenetrability*, *inertia*, *divisibility*, *porosity*, *compressibility*, and *elasticity*. All these terms have been explained in the elementary course. In consequence of these universal properties all forms of matter take up space, offer resistance, possess weight, and can transfer motion.

Specific Properties of Matter.—Characteristics possessed by certain substances only are: *tenacity*, *ductility*, *malleability*, *hardness*, *viscosity*, *mobility*, *cohesion*, and *adhesion*.

States of Matter.—There is a gradual transition from the ideal condition of a *perfect solid* through several stages to what is known as *radiant matter*. The conditions of matter which have been discussed are in order: (1) perfect solid; (2) rigid solid; (3) soft solid; (4) viscous liquid; (5) mobile liquid; (6) vapour; (7) matter in critical state; (8) gas; (9) radiant matter.

Rigidity is that property of solids which distinguishes them from fluids. If the ratio of the amount of deformation produced to the deforming force is known in any body we can describe its physical state thus, if the fraction

$$\frac{\text{Deformation}}{\text{deforming force}} = \text{some } \textit{constant} \text{ amount}$$

the body is a *perfect solid*; if, on the contrary, the value of the fraction increases with the lapse of time it is a *fluid*. The deformation produced is known as a *strain*, the deforming force is of the nature of a *stress*; the above ratio may thus be written $\frac{\text{strain}}{\text{stress}}$; if this equals zero, and remains so, the body is *absolutely rigid*; when its value is very small it is a *rigid* body, when great it is a *soft* solid.

When in the case of **Fluids** the value of the fraction increases with the lapse of time we distinguish between *viscous* and *mobile* fluids; thus in the former case the change with the lapse of time is small, in the latter great.

Vapours are gases which are easily converted into liquids by a diminution of temperature. *Saturated* vapours are liquefied by a slight amount of cooling; *unsaturated* vapours may be considerably cooled without liquefaction.

Critical Temperature.—No pressure, however great, will liquefy gases which are above the temperature known as the *critical temperature*. Since this temperature for the so-called "permanent" gases is very low, these can only be liquefied by great pressure and a very low temperature.

Extensibility.—

$$\frac{\text{Increase in length}}{\text{original length}} = \text{extension};$$

$$\frac{\text{extension}}{\text{extending force}} = \text{extensibility.}$$

Extension cannot go on indefinitely; a point is reached when the body's cohesion is overcome, this particular extending force is called the *breaking weight*.

Compression is the converse of extension.

Elasticity.—When a body is subjected to compression, the force which acts in opposition to it in consequence of the body's *elasticity* is known as *restitution*. The ratio of the force of restitution to that of compression is called the *co-efficient of elasticity*. Were this ratio 1 the body would be *perfectly elastic*; were it 0 it would be completely *inelastic*. All known values fall between these limits, or all bodies are *imperfectly elastic*. Elasticity may be developed in solids in at least four ways, viz., by pressure, by pulling, by bending, and by twisting.

QUESTIONS ON CHAPTER I.

(1) State some differences between solids, liquids, and gases.

(2) Give some reasons for believing that matter exists in other states besides solids, liquids, and gases.

(3) How would you distinguish between a perfect solid, rigid solids, soft solids, viscous liquids, and mobile liquids?

(4) Define rigidity, and state how the property enables a solid to be distinguished from a liquid.

(5) What is the difference between a gas and a vapour?

(6) Would it be possible to compress carbon dioxide gas into a liquid if the temperature of the gas was kept at 60° C? Give reasons for your answer.

(7) Describe an experiment to show that radiant matter possesses energy.

(8) What is meant by the critical temperature of a gas?

(9) Explain the sentence—"Vapours are gases below their critical temperatures."

(10) Define elasticity, and describe experiments to prove that it may be developed by pulling, bending, and twisting.

(11) How would you prove that the amount a piece of india-rubber cord stretches when pulled depends upon the stretching force, the length of the cord, and the thickness?

(12) Describe an experiment to illustrate torsion.

(13) Describe in detail an experiment by means of which you could determine the "modulus of elasticity" of a material substance such as copper.

(14) What do you understand by torsion? How would you proceed to show that whatever the amplitude of the oscillations of a weight attached to a twisted wire may be, the time in which they are performed remains constant?

(15) What are the distinguishing characteristics of a solid? Explain carefully the reasons for regarding jelly as a soft solid, and sealing wax as a very viscous liquid.

(16) What conditions would a material body have to obey in order that it might be classified as perfectly rigid?

(17) Explain the expression "co-efficient of rigidity." Name some substances in which this co-efficient is high, and some in which it is low.

(18) What is a vapour? Distinguish between saturated and unsaturated vapours.

(19) Vapours are gases below their critical temperatures. Explain this statement, showing clearly that you understand the expression "critical temperature."

(20) Define precisely what is meant by "compression." What follows if the force of compression to which a material body is subjected is continually increased?

CHAPTER II

WORK AND ENERGY

Work.—It will only be necessary in this place to briefly recapitulate the elementary notions of work with which the reader has become familiar. Work is done by a force, either when it acts upon a body producing an acceleration in its velocity, or when it maintains a uniform velocity in a body in opposition to resistance. A body falling towards the earth from a height has work done upon it by the earth's attractive force, and the well-known result is that the body moves with a regularly increasing velocity. The velocity increases according to a uniform acceleration of 32·2 feet per second in every second. Work is done by a locomotive which maintains a uniform rate of motion in a train, since it is continuously overcoming the resistance of the air, and that due to friction between the wheels and the rails. Nor is there any difference between this work of acceleration and the work against resistance, as will become clear if it is borne in mind that whether we allow a mass to drop from the hand and move with the above-mentioned acceleration, or attach it to a string which is passed over a cylinder and cause it, by applying resistance, to travel towards the earth with a uniform velocity, in both cases the final result is the same. Under the first conditions work of acceleration is done, and in the second case work against resistance.

How Work is Measured.—In measuring work, therefore, all that is necessary to be done is to find the product of the number of units of force acting, and the distance in units of length through which the point of application is moved, provided that the distance is measured parallel to the line along which the force acts.

Work = force × distance (measured as above) through which it acts.

In the case of a body raised from the earth the work done is equal to the force overcome, viz. that equal to the weight of the body, multiplied by the distance through which it is raised. In calculating the amount of work under such circumstances, we shall have, in order to find the weight which is overcome, to multiply the body's mass by the value of the attractive force or the earth at the place where the work is done. This can be represented by an equation, if M equals the mass of the body, g the attractive force of the earth, and h the distance through which the body is raised, then we have

$$\text{Work done} = \text{mass} \times \text{gravity} \times \text{distance the body is lifted}$$
$$= \mathrm{M}gh.$$

Units of Work.—To understand the units in which the product $\mathrm{M}gh$ is expressed, we must recall what has been learnt in the earlier consideration of this part of our subject. If we use the pound as the unit of mass and the foot as that of length, we have as our unit of force that force, which acting on the mass of a pound for one second, generates a velocity of one foot per second. But experiment shows that in the latitude of London a force equal to the weight of a pound acting on the mass of a pound at the sea-level generates in it a velocity of 32·2 feet per second. The unit of force is therefore $\frac{1}{32{\cdot}2}$ of that equal to the weight of one pound, or about the weight of half an ounce. This unit force is called a *poundal.*

Referring back to our value for the work done in raising a body, the force overcome in the equation is expressed by $\mathrm{M}g$, that is, as poundals—and the final product is expressed in terms of this unit force in what are called *foot-poundals.* The practical unit of work is different. It is the work done in raising the mass of a pound through a distance of one foot. Evidently this is a variable unit, since the weight of the mass of a pound varies with the latitude. This variation is in practice neglected, and the unit is spoken of as the *foot-pound.* The student will at once see that to express foot-pounds in foot-poundals we must multiply by the value of g.

The Rate of Doing Work.—The same amount of work is done whatever time is occupied in raising the mass we have been considering. The only two factors which influence the total work performed are the force acting, or the resistance overcome, and the distance through which either the resistance is overcome or the force acts. When the question of time is introduced, the discussion becomes that of the *power* of the agent doing the work. The greater the rate at which the agent can work, be the agent man or machine, the greater is its power. In fact, *power is the rate of doing work.* Among engineers it is customary to adopt Watt's estimate as to the rate of working of a good horse, which he puts at 33,000 foot-pounds in a minute, and to call this rate of working a *horse-power*, using the abbreviation H.P. to signify it. Since the value of the foot-pound varies with the latitude, so must also that of a horse-power.

Capacity for Doing Work. Energy.—The capacity which a body possesses of doing work, either by virtue of its motion or by that of its position, is called its energy. The energy of bodies in motion is known as *kinetic energy.* Familiar instances of this order of energy are found in the flying bullet, the moving stream, the wind, and many other common instances of matter in motion.

Measure of Kinetic Energy.—When we wish to measure the energy of such moving bodies we have to find an expression which will be equal to the amount of work these bodies are capable of performing when the whole of their energy is converted into work. Such an expression is found from first principles as follows :—

If we take the unit of acceleration as equal to an increasing velocity of one foot per second in one second, an acceleration of f means an increase of velocity of f feet per second in one second. Suppose a body starts from rest, at the end of the first second it has a velocity of f feet per second, at the end of the next second $2f$, at the end of t seconds ft feet per second. Or if v=change of velocity in t seconds we can write

$$v=ft. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The space travelled over by a body in one second is equal to its average velocity, and that travelled over in t seconds is equal to its average velocity multiplied by t. If it starts from rest and travels for one second finishing with a velocity of v feet per second, its average velocity is $\frac{1}{2}v$ during this time, and

$$\therefore \quad s = \tfrac{1}{2}vt \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

Substituting value of v from equation (1) we get

$$s = \tfrac{1}{2}ft \times t = \tfrac{1}{2}ft^2,$$

or since from (1) $t = \dfrac{v}{f}$ we can write equation (2) thus

$$s = \tfrac{1}{2}v \times \frac{v}{f} = \tfrac{1}{2}\frac{v^2}{f}, \text{ from which}$$

$$v^2 = 2fs. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If the body is moving freely towards the earth its acceleration is g, and equation (3) becomes

$$v^2 = 2gs. \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Still considering the body falling towards the earth, the work done by it in moving through any distance s is equal to the weight of the body multiplied by that distance, viz., Ws or Mgs (p. 17), or work done $=$ M$gs = $ M $\dfrac{v^2}{2}$ from equation (4) above.

This expression $\dfrac{Mv^2}{2}$ is therefore a measure of the energy of a falling body, and gives us a means of calculating the energy possessed by any body in motion in terms of its mass and its velocity. If we wish to express it in foot-pounds we shall, as we have seen, divide its value by g.

Kinetic energy, or the energy of moving bodies, is equal to one-half the product of the body's mass and the square of its velocity. But the mass and the velocity must be expressed in suitable units.

Potential Energy.—We have just seen that the kinetic energy possessed by a moving body is equal to the work which would have to be done upon it to make it travel over its journey in the reverse order under the same conditions. If, for instance, a body is lifted from the earth in opposition to the gravitational stress, the amount of work done upon it is just sufficient to cause it to travel back to the earth and arrive with a velocity expressed by the equation $V = \sqrt{2\,gs}$, provided it were simply released and put into a condition which permitted free motion. If we imagine the body which has been thus raised to be placed upon a shelf it possesses a store of energy which it holds as long as it is on the shelf. This stored up energy is known as *potential energy.*

But energy can be stored up in many other ways. Watches work by gradually converting the stored up energy in their springs into the kinetic energy of their moving parts. Clocks go in the same manner—or else, as in the "grandfather's clock," by using the energy stored up in their raised weights.

Combustion is another means of translating potential into kinetic energy. Wood or coal is possessed of a store of potential energy, which is a measure of the amount of work done by the chlorophyll in building up (from the carbon dioxide in the air and the substances absorbed by the plant's roots) the chemical compounds of which they are built. Similarly articles of food are reservoirs of potential energy. Living animals are continually using up this energy in performing the various movements which attend their life. This last instance of the conversion of potential into the energy of motion constitutes what the physiologist calls *Kataboly*. The opposite process of *Anaboly* consists in the building up of complex chemical compounds from simpler substances by the expenditure of work.

It is interesting to note that the Vegetable Kingdom serves the purpose of changing the energy of the sun's rays into the potential energy of both fuel and food. We have seen this in sufficient detail in the case of fuel; and since all animals are dependent either directly or indirectly (through the agency of other animals) upon plant life for their food, it is clear that it is equally true of food.

A reference must be made to the potential energy of a Head of Water. That water, under such circumstances, possesses a store of energy is recognised by everybody; and that it owes this potential energy to the sun's activity is immediately obvious when we remember that the sun causes rain by bringing about evaporation from the water on the earth's surface, and that the energy of the sun's rays is largely consumed in raising this water to a higher level, in which position as in the case of the raised mass already considered, it is so situated that it can, under suitable conditions, give out its store of energy in a kinetic form.

Again, since by the combination of certain elements a definite amount of energy becomes kinetic, the mere existence in their elementary state of these forms of matter represents so much potential energy, but its amount and importance is not great.

Finally, we have another available source of potential energy in what Tait has called Tidal Water-power. If we entrap part of the water of the ocean when the tide is high, we can, after the retreat of the tide, utilise the potential energy of the water prevented from retreating.[1]

Available Sources of Kinetic Energy.—The student must always remember that nearly all our energy is derived either directly or indirectly from the sun. This applies equally to both kinetic and potential energy. But as regards terrestrial sources of kinetic energy, we cannot do better than follow Tait in enumerating them under the three heads: (1) winds; (2) currents of water, especially ocean currents; (3) hot springs and volcanoes. But the first two of these are immediately dependent upon the energy of the sun's radiations, as we shall see more fully later, though already the student has learnt sufficient on these subjects to appreciate the truth of the statement.

Conservation of Energy.—The amount of energy in the universe is constant. Though it is continually changing its form it is never created and never destroyed. Side by side with the parallel truth of the indestructibility of matter, it lies at the foundation of all chemical and physical science. The recognition of this generalisation has done more, perhaps, to help forward our knowledge of physical science than any other advance in learning. The statement is the outcome of the work of many men, chief among whom were Joule, Golding, and Helmholtz; and simple though the bare expression of it may seem, yet it was only by years of experiment that its truth was thoroughly established.

It was not until Heat, Light, Sound, etc., were all found to be forms of energy, that is, it was not until the beginning of this century, that it became possible for men of science even to suspect what is now almost a matter of common knowledge. As long, for instance, as heat was regarded as a fluid, the transference of the energy of motion into the heat of friction was difficult to trace and explain; but the experiments of Rumford and Davy, with which our reader has already become acquainted, in establishing the fact that heat was in reality a form of energy, made this matter quite clear. Similarly it was only after the old corpuscular theory of light, which was accepted by Newton, had been demonstrated to be insufficient to explain all the phenomena observed, and had been proved not to harmonise with some of the observed facts, that the present explanation of light being a wave motion of the luminiferous ether was established, and light was recognised as another manifestation of energy. The same development of ideas is manifest in every one of the branches of physical science; and now all physical and chemical forces are explained by reference to this most important law, that the sum total of the energy of the universe is never decreased or increased. If we represent each of the sources of energy, which we have enumerated, by letters, *e.g.*, A, for the kinetic energy of bodies in visible motion; B, for the potential energy of bodies in an elevated position; C, the potential energy of food and fuel, and so on, the principle of the conservation of energy states that $A + B + C + D + \text{etc.} = \text{a constant quantity}$.

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[1] The student who is anxious to thoroughly understand what is known about energy should consult Tait's *Recent Advances in Physical Scienoe.*

Transmutation of Energy.—One kind of energy can cease to exist in that particular form and can assume another condition. Indeed, one form of energy can assume almost any other form. The study of these transformations of energy constitutes the whole subject of Physics, and we can only indicate in the briefest and most general manner what the nature of these transmutations is. Starting with the kinetic energy of visible motion we can have this energy changed into heat, as when a bullet strikes a target and its energy of motion is converted into heat often sufficient to melt the bullet. Or, this motion can be converted into vibrations sufficiently rapid to cause waves in the atmosphere which give rise to the phenomena of sound. Beginning with the energy of heat, we can, by suitable contrivances, change it into the energy of moving bodies, as in the thousand and one machines which are used in the different manufactures; or, with the help of different metals in contact, as in the thermopile, we can have it disappearing as heat and appearing as the energy of electric currents; or, again, as the student will have learnt in his study of chemical changes, heat can be transformed into the energy of chemical action. Instances of these transformations could be multiplied indefinitely, but sufficient has been said to indicate what is understood by the expression which begins this paragraph.

Motion of a Pendulum.—The motion of a pendulum affords an interesting example of the two forms of energy. At the end of its swing, in the position A (Fig. 7), the bob of the pendulum possesses potential energy enough to carry it through half an oscillation, that is until it reaches its lowest position N, when the whole of the energy of position which it possessed at A is expended, as it can reach no lower position. But though it lacks potential energy, since it is a mass moving with the velocity it has gained in its passage from A to N, it possesses energy of motion or kinetic energy enough to carry it up to its next position of rest at A′—where the only energy it will have will be again potential. Through the next oscillation from A′ to A it will pass through just the same transformation again, and in every part of the swing the sum of the kinetic energy and potential energy is the same.

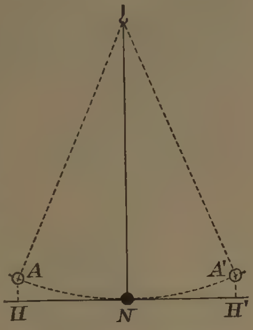

FIG. 7.—Motion of a Pendulum.

Degradation of Energy.—The general tendency in all transformations which energy undergoes is towards a degradation in its character. All forms of energy are not equally useful to us. The study of heat has demonstrated that it is only by its passage from a hot to a cold body that we are able to convert heat into work. This fact is laid down in the so-called Second Law of Thermo-Dynamics, which has been expressed by Maxwell in the following words:—"It is impossible, by the unaided action of natural processes, to transform any part of the heat of a body into mechanical work, except by allowing heat to pass from that body into another at a lower temperature." Hence, since experience shows that all forms of energy ultimately assume the condition of uniformly diffused heat, it is apparent that when once all the energy of the universe has assumed this form there will be no further possibility of any other transmutation. The eventual assumption of the form of diffused heat by all the forms of energy with which we are acquainted is what is referred to by the expression degradation of energy. A few instances of this degradation will perhaps convince the student of its reality. Let us study the case of a moving bullet. It begins to travel in say a horizontal direction, with a high initial velocity, which is continuously diminished until eventually the bullet comes to rest. At the start it possesses a store of kinetic energy equal to $\frac{1}{2}$ mass × $(\text{velocity})^2$ or $\frac{mv^2}{2}$; some time after the completion of its journey it lies on the ground with no energy at all. What has become of this energy? From Newton's first law of motion we know that in the absence of impressed forces the bullet will continue to move for ever in a straight line with its initial velocity. Since it comes to rest after a time, it must be under the influence of impressed forces during its flight. One of these is the friction of the atmosphere which retards its motion, another is the gravitational stress due to its own and the earth's masses. The former is overcome at the expense of some of the bullet's energy of motion, and this friction is used in warming the atmosphere and the bullet. The other impressed force causes it to travel along a parabolic path which represents the resultant of its initial velocity in a horizontal direction, and a vertical velocity measured by the relation, $\text{velocity}^2 = 2\,(\text{gravity} \times \text{altitude})$ or $V^2 = 2gh$, depending upon the height (h) through which it has fallen. When it comes in contact with the earth it strikes it with a certain resultant velocity which we will leave our reader to calculate. The kinetic energy of motion is at the moment of impact with the earth converted into heat, which warms the bullet and the earth. Eventually, by conduction and radiation, the bullet and the earth take the temperature of surrounding objects, and we see that the store of energy with which we started has become degraded into that of diffused heat.

Or, we may consider the case of an engine which is supplied with energy from the store of potential energy in the fuel. The object of the engine is to convert this potential energy of the fuel into mechanical work. If the engine were perfect it would be able to convert the whole of this store of energy into work. But actual engines are by no means perfect, they are only able to convert a fraction of the available energy into work. The ratio of the work done by the engine to the available store of energy is known as the efficiency of the engine. Part of the energy of the fuel is dissipated in warming the parts of the mechanism, part in heating and expanding the products of combustion, another fraction in overcoming friction and so on. Another portion is lost, viz., that represented by the heat of the water in the condenser of those engines which possess them. But the sum of all these amounts, and others we have not mentioned, together with the work done by the engine, does exactly equal the potential energy of the fuel.

The Mechanical Equivalent of Heat.—Since heat may, by a suitable contrivance, be converted into mechanical work, or work may be expended in producing heat, the question

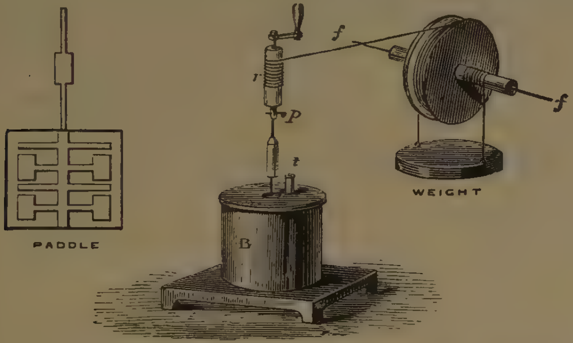

Fig. 8.—Joule's Fluid Friction Apparatus for determining the Mechanical Equivalent of Heat.

naturally arises : How much heat can be developed by the expenditure of a given quantity of work? Or, putting it in another way : How much work can be produced by the complete conversion of a given quantity of heat into it? Joule first experimentally determined this value, which is known as the *mechanical equivalent of heat.* It must be pointed out that from the conservation of energy it follows that there is a mechanical equivalent for each of the forms of energy which we have had before our notice in this chapter. Joule determined this constant for heat in a variety of ways, but we shall content ourselves with describing two of them. It will make the matter much clearer if we remind our reader that a foot-pound of work is performed when the mass of a pound is raised through a height of one foot from the earth. Also that by the expression a thermal unit, we mean the quantity of heat necessary to raise the temperature of a pound of water through one degree Centigrade.

Joule's Fluid Friction Apparatus.—Joule's apparatus consisted essentially of two parts:—1. The contrivance for the performance of work; 2. The apparatus for converting this into heat. The first comprised two heavy weights of known mass, which were attached to cords which passed over two pulleys. The cords from the pulleys passed round an axis, as shown in the figure. The pulleys were specially supported upon friction wheels to diminish as much as possible the amount of work lost by friction. The second part of the apparatus included a copper vessel, in which four vanes were set radially. The vanes were of such a pattern that a paddle of the design shown in the figure could just pass through them. This prevented the water, with which the copper vessel was filled, from being bodily whirled round with the paddle. As the paddle rotated its energy of motion was converted into heat by the friction of the water, and this heat warmed the water. Eight paddles were radially fixed to a spindle, which could be attached by a peg to the axis which receives the cords from the pulleys.

The work expended in causing the rotation of the paddles was directly measured by the fall of the known masses through measured heights. The amount of heat developed was equal to the product of the number of pounds of water in the vessel B, and the number of degrees through which its temperature was raised. This last number was ascertained by means of a very delicate thermometer which was introduced into the vessel of water. Every precaution was taken to avoid a loss of mechanical work by friction in the parts of the apparatus, and also to avoid loss of heat by radiation and conduction from the copper vessel. The average of a large number of experiments made by Joule gave the value of the mechanical equivalent of heat as 1,390 foot-pounds. Or, *to raise the temperature of one pound of water through one degree Centigrade requires an expenditure of* 1,390 *foot-pounds of work.* To raise the temperature of a pound of water through 1° F. requires 772 foot-pounds.

Joule also applied the principles of fluid friction in another way, viz., by rotating two discs of cast iron which pressed against one another, both of them being immersed in a cast-iron vessel filled with mercury. The results obtained under these circumstances agreed very well with those obtained by the previous method.

Joule's Determination of the Mechanical Equivalent of Heat by means of Magneto-Electricity.—This method depends upon one or two facts which we must bring before the student's notice. If a metal disc be rapidly rotated between the poles of a strong electromagnet it is found that electric currents are caused to flow round it. These currents, which are induced in the metal plate, cease to flow when its rotation is stopped ; moreover, these induced currents flow in such a direction that they tend to stop the rotation of the disc. The first transmutation of energy is the conversion of the energy of rotation into that of the electric currents flowing round the metal plate. But this is followed by the transformation of the energy of the electric currents into that of heat. Such a plate is only rotated between the poles of a very powerful electro-magnet by the expenditure of a great amount of mechanical work, and this is eventually converted into sufficient heat in the plate to make it too hot to touch. By measuring the amount of work expended in rotating the disc, and also the quantity of heat developed in it, it is easy to calculate the mechanical equivalent of heat.

The Pendulum.—We have already regarded the pendulum as affording a good example of the conservation of energy, and as it provides an excellent method for the determination of the value of the acceleration due to gravitation, and exemplifies the application of several general principles which it is desirable that the student shall become conversant with, we shall consider more fully what laws govern its motion.

Motion in a Circle.—It will be remembered that the first law of motion teaches that any object, once set in motion, moves in a straight line unless the action of external force prevents it from doing so. If, therefore, a body is moving in a curve, this is because it is being continually pulled out of its rectilinear path by some force. Imagine a ball at the end of a string being swung round by the hand. Let A (Fig. 9) represent the ball and AB the string, the hand being held in the position of B. It is clear that two forces are acting upon the ball,—(1) the inertia of the ball which tends, in accordance with Newton's first law of motion, to make it travel along the line AC; and (2) the pull of the string along the line AB. The direction of the resultant of these two forces falls between the directions of the forces themselves and causes the ball to travel along the line AD. The line, CD thus represents the pull of the string. Whenever an object moves round a central point in a similar manner, whether the pull towards the centre is represented by the tension of a string or by an attraction of some kind, the actual circular path travelled represents the resultant of two forces acting upon it. It can be very simply proved that if the mass of the body, the ball in our example, moving along a circular path be represented by m, and the velocity with which it is travelling by v, while the radius of the circular path be r, then the value of the force represented by oc in the figure is given by $\frac{m \times v^2}{r}$.

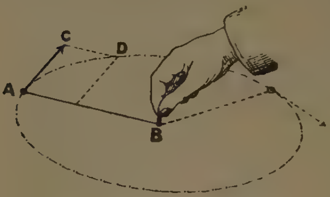

FIG. 9.—Motion in a Circle.

Referring again to our instance of the ball, its motion in a circular path gives rise to a tension in the string which is equal to the product of the ball's mass and the square of its velocity, divided by the length of the string.

Laws of the Pendulum.—A simple pendulum is an instance of a body moving in a circular path. Such a pendulum consists of *a mass suspended by a light cord from a fixed point and caused to oscillate in a vertical plane.* Such oscillation is shown in Fig. 7. The motion from A to A′ or from A′ to A is called one *vibration* or one *oscillation.* The arc A N A′ is referred to as the *amplitude* of the vibration, and the time taken by the mass to travel from A to A′ is called the *time of oscillation.* The time of oscillation can, by a simple application of dynamical principles, be shown to be given by the expression—

$$\text{Time of oscillation} = 3\tfrac{1}{7}\sqrt{\frac{\text{length}}{\text{gravity}}}, \text{ or } t=\pi\sqrt{\frac{l}{g}};$$

where t stands for the time of oscillation, l for the length of the cord, g for the value of the acceleration due to gravitation, and π for the ratio ($\frac{22}{7} = 3\cdot1416$) between the circumference and diameter of a circle.

Expt. 2.—Tie small leaden balls with hooks attached to pieces of string, and fix the free end of the string to a suitable support (Fig. 10). Let the strings be of different lengths, the size of the balls being the same. Ascertain the time of oscillation for each pendulum by recording the time taken to perform say twenty vibrations. Repeat the observation several times, and take the average of the results. Measure the lengths from the centre of the ball to the point of attachment of the string, and show that the times of oscillation of the different pendulums are in the proportion of the square roots of the lengths of the strings, or $t : t_1 = \sqrt{l} : \sqrt{l_1}$. Also show, what is the same thing, that the squares of the times of oscillation are in the proportion of the lengths of the pendulums, or $t^2 : t^2_1 = l : l_1$.

Expt. 3.—Perform a similar experiment to that just done and count the number of vibrations in a given time, say a minute, and show that the square of the number of oscillations are in the inverse proportion of the lengths of the strings, or $n^2 : n_1^2 = l_1 : l$.

Expt. 4.—Prove that for swings of small amplitude the time of a vibration is independent of the amplitude.

Expt. 5.—Substitute weights of different masses, and demonstrate that the mass of the body does not affect the time of swing.

Expt. 6.—Make the length of the string as nearly as possible $39\cdot14$ inches, and show that the time of oscillation is one second.[1]

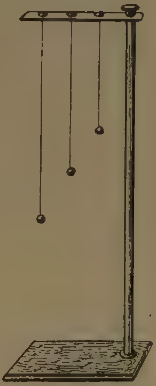

Fig. 10.—Balls suspended by Strings of different lengths, to illustrate Pendulum Motion.

Variation in the value of "g."—The form of the earth is not exactly spherical, but that of an oblate spheroid, or a sphere flattened at the poles. This causes a variation in the distance of the earth's surface from its centre, *i.e.* a variation in the length of the earth's radius. This is one of the causes which results in a different value for the acceleration due to gravity in different latitudes.

The rotation of the earth is another disturbing influence.

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[1] The length of the seconds pendulum at Greenwich is 39·139 inches.

While places at the equator are carried round with a velocity of over a thousand miles an hour, those near the poles have but a very small velocity of rotation, while the pole itself is at rest. It is clear that if we consider a mass at the equator its tendency is to obey the first law of motion and to fly off at a tangent, and part of the force of gravitation is expended in preventing this flight—the remainder of the gravitational stress is operative as the weight of the mass under consideration. At the pole there is no tendency to move off tangentially, and the whole of the force of gravitation is felt as the weight of the body. For this reason alone the mass would weigh less at the equator. At places intermediate between the poles and the equator the diminution in the weight of the body, or the diminution in the acceleration due to gravity, is less; it diminishes as the nearness to the pole is increased.

The Pendulum as a Measure of the Variation in the value of "g."—From the equation on p. 28 for the time of oscillation of a pendulum we can at once obtain an expression for the value of *g*. Thus:

$$t=\pi\sqrt{\frac{l}{g}};$$

squaring both sides, we have

$$t^2=\frac{\pi^2 l}{g},$$

so that

$$g=\frac{\pi^2 l}{t^2}.$$

To find the value of the acceleration due to gravity in any place, therefore, all we have to do is to set a pendulum of known length vibrating, and to ascertain its time of oscillation. If we multiply the length of the pendulum by the square of $\pi(=9{\cdot}8696)$ and divide by the square of the time of oscillation we obtain the value of *g*. Thus if the experiment is performed at Greenwich with a seconds pendulum, whose length there is 39·139 inches, the equation would be:

$$g=\frac{9{\cdot}8696\times\frac{39{\cdot}139}{12}\text{ft.}}{1^2}$$
$$=32{\cdot}2\text{ ft.}$$

Compound Pendulums.—A simple pendulum is an ideal; it does not exist in practice. All pendulums consist of a bob attached to a rod, and in such arrangements the rod itself has a considerable weight and complicates the expression for the time of an oscillation. But in every case we can imagine a simple pendulum which performs an oscillation in the same time as does the *compound pendulum*, as it is called (Fig. 11). Such a simple pendulum is referred to as the *simple equivalent pendulum*. That particle in the compound pendulum whose time of oscillation is the same as the simple equivalent pendulum is said to be situated at the centre of oscillation. Similarly the length of a compound pendulum is estimated by that of the simple equivalent pendulum.

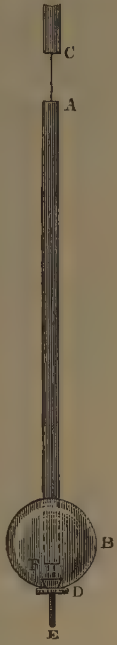


FIG. 11.—A Compound Pendulum.

CHIEF POINTS OF CHAPTER II.

Work is the act of overcoming resistance, or causing change of velocity.

Work is measured by finding the product of the number of units of force acting and the distance, in units of length, through which its point of application is moved. This distance must be measured parallel to the line along which the force acts.

Work = force × distance.

Units of Work.—*Foot-poundal.*—Since a force equal to the weight of a pound acting on the mass of a pound at the sea-level generates in it a velocity of 32·2 feet per second—the unit force, or that which would generate a velocity of 1 foot per second, is equal to the weight of $\frac{1}{32 \cdot 2}$ of a pound. The unit force acting through one foot performs one *foot-poundal* of work.

Foot-pound.—This is a variable unit. It is the work done by a force equal to the weight of one pound acting through one foot.

Power is the rate of doing work. A *horse-power* is 33,000 foot-pounds per minute.

Energy is the capacity for doing work.

Energy

Kinetic,	Potential,
due to motion, as shown by a moving cannon ball and a flowing river.	due to position, as a mass at the top of a tower and a wound-up spring.

Measure of Kinetic Energy.—The measure of the kinetic energy of a moving body is equal to one-half the product of its mass and the square of its velocity; or

$$\text{Energy of moving body} = \frac{Mv^2}{2} \text{ foot poundals} = \frac{Mv^2}{2g} \text{ foot pounds.}$$

Available Sources of Terrestrial Kinetic Energy.—1. Winds. 2. Currents of water, especially ocean currents. 3. Hot-springs and volcanoes. The first two are directly dependent upon the energy of the sun's radiations.

Examples of Potential Energy.—(1) Due to position, as that of masses raised against the force of gravity (the weights of a clock), or bodies displaced against the force of their own elasticity (wound up watchspring). (2) That of combustible bodies like wood, where the energy of the sun's rays is rendered potential in its component chemical compounds by the action of chlorophyll. (3) Potential energy of foods. (4) Potential energy of a head of water. (5) Potential energy of bodies in an elementary condition (elements). (6) Tidal water-power.

Conservation of Energy.—Energy is never lost, but only changed in form, and whatever transformations take place the sum total of the kinetic energy and potential energy remains the same. If A stands for kinetic energy of bodies in visible motion; B, for potential energy of bodies in an elevated position; C, the potential energy of food and fuel, etc., the principle of the conservation of energy states that:—

A + B + C + D + etc. = a *constant* quantity.

Transmutation of Energy.—One kind of energy can cease to exist in that particular form and can assume another condition. Indeed, one form of energy can be converted into almost any other condition.

Degradation of Energy.—All forms of energy ultimately assume the condition of uniformly diffused heat; and when once all the energy of the universe has been degraded to this condition there will be no further possibility of any other transmutation.

Mechanical Equivalent of Heat.—There is a mechanical equivalent for every form of energy. Joule first determined it in the case of heat. He found that *to raise the temperature of one pound of water through one degree centigrade, an expenditure of* 1390 *foot pounds of work is necessary.*

Method of Determining Mechanical Equivalent of Heat.—Two plans are described in the chapter. (1) By causing paddles to rotate by means of falling weights and making the rotating paddles warm a known mass of water. (2) By means of magneto-electricity. A metal disc is caused to rapidly rotate between the poles of a strong electro-magnet. The amount of mechanical work expended in rotating the disc is measured and also the quantity of heat developed in the disc by the induced electric currents. From these data the equivalent can be calculated.

Angular Velocity.—If a body moves in a circle a force must act toward the centre of the circle. If the force suddenly ceases to act the body moves on in a straight line, and thus departs from the centre of the circle. Hence curvilinear motion is an effect due to the inertia of the moving body and a force which pulls the body towards the centre of motion.

A Simple Pendulum is an instance of a body moving in a circular path. Such a pendulum may be defined as *a mass suspended by a light cord from a fixed point and caused to oscillate in a vertical plane.*

The *time of oscillation* of a pendulum varies inversely as the square root of the value of the acceleration due to gravity, and directly as the square root of the pendulum's length :

$$t = \pi\sqrt{\frac{l}{g}}.$$

Or, we may say, the squares of the times of oscillations of two pendulums are to one another as their lengths; and the squares of the numbers of the oscillations are inversely as their lengths.

Value of "g."—If we know the length of a pendulum and the time it takes to make a complete oscillation we can find the value of the acceleration due to gravity, thus :

$$g = \frac{\pi^2 l}{t^2}.$$

QUESTIONS ON CHAPTER II.

(1) Compare the rate of vibration of a pendulum 36 inches long with one 18 inches long. If you took a pendulum of any given length from London to the equator, what change would be noticed in its rate of vibration?

(2) State what is meant by the mechanical equivalent of heat, and explain a method by which it has been determined.

(3) What is a simple and what a compound pendulum? How would you experimentally prove that the squares of the times of oscillations of two pendulums are in the proportion of their lengths?

(4) How can a pendulum be used to measure the acceleration due to gravity?

(5) Under what circumstances is it correct to say that work has been done? How are quantities of work measured, and what units are employed?

(6) Distinguish between kinetic and potential energy. By reference to the case of an oscillating pendulum explain what is meant by the expression, "conservation of energy."

(7) Name several ways in which energy can be stored up, and describe fully what you mean by the potential energy of a "head of water."

(8) Explain the terms "transmutation of energy," and "degradation

of energy." Name any transmutations or degradations which occcur in the case of a bullet fired from a gun, which after its flight through the air strikes the ground.

(9) What is understood by the "mechanical equivalent of heat"? Who measured it first, and how?

(10) Describe experiments to illustrate some simple laws controlling the rate of motion of a pendulum.

(11) What difference would be observed in the rate at which a pendulum would vibrate if taken from London (*a*) towards the poles, (*b*) to the equator?

CHAPTER III

HEAT AND TEMPERATURE

Introductory.—The construction, graduation, and use of the ordinary forms of alcohol and mercury thermometers are fully described in the volume to which this is supplementary ; we may assume the student is, therefore, familiar with these facts, and take it for granted that he is acquainted with the reasons which govern the choice of liquid, tube, and scale. In the early part of the present chapter we shall call attention to several forms of registering thermometers and pyrometers, describing their construction, and explaining the principles on which their action depends, together with the uses to which they are put.

Maximum and Minimum Thermometers. — In weather reports, as every one knows, it is usual to record both the highest temperature reached during the twenty-four hours under consideration as well as the greatest degree of cold which has been experienced in the same interval of time. The former record is obtained by the use of a maximum thermometer, the latter by a minimum thermometer.

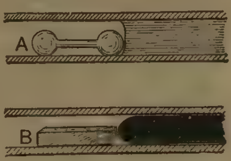


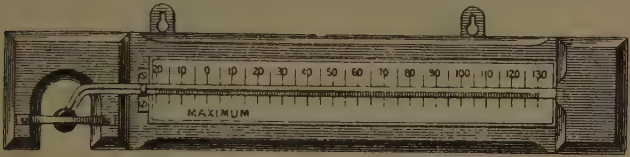
FIG. 12.—A, an Index in the Liquid of a Minimum Thermometer ; B, an Index pushed forward by the Mercury of a Maximum Thermometer.

One of the simplest maximum thermometers consists of an ordinary mercury instrument into the stem of which has been introduced, before sealing it, a piece of thin iron rod, which works loosely in the tube (Fig. 12 B). When the mercury expands it pushes the piece of wire before it, and on contracting leaves the wire at the highest place to which it has been pushed. The reading indicated by that end of the wire nearest to the mercury is the maximum temperature which has been reached. To reset the thermometer the piece of wire may be drawn back to touch the mercury by the attraction of a small horse-shoe magnet. The instrument is suspended in a horizontal position.

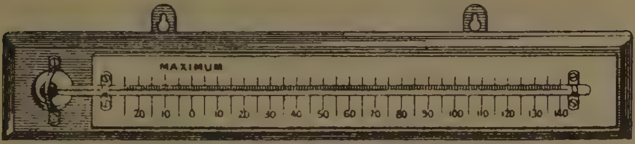
When measuring low temperatures it is usual to use an alcohol thermometer, and this can easily be made to itself register the lowest temperature experienced. Into the stem of the thermometer either a fine capillary tube or a black dumb-bell-shaped index (Fig. 12 A) is introduced. When the temperature falls, the alcohol in contracting drags back the marker, as a result of the adhesion between it and the index. On a rise of temperature occurring the index remains stationary, the alcohol flowing either through it or round it, as the case may be, but causing no further displacement of the marker. The end of the index most removed from the bulb will register the lowest temperature which has been experienced.

Phillips's Maximum Thermometer.—This form, made by Casella on a plan suggested by Professor Phillips, is a mercury thermometer, with a very fine bore, from which all the air has *not* been driven (Fig. 13). The column of mercury is broken by means of a bubble of air, and it is on the alteration in volume of this intercepted air bubble, which it experiences as the temperature changes, that the instrument depends. An increase in temperature causes the mercury in the bulb to expand and push the air bubble and detached thread of mercury along. But as the temperature falls, and the main part of the mercury contracts, the air bubble expands, since the pressure upon it is reduced. The separated thread remains unmoved and hence serves as an index which records the highest temperature. The thermometer is used in a horizontal position and is set by making the air bubble as small as possible.

Negretti and Zambra's Maximum Thermometer.—This form of instrument differs from an ordinary mercury thermometer in one detail only, viz., that the bore of the thermometer, just above the bulb, is almost completely filled by a glass or enamel obstruction, as shown in Fig. 13. When the temperature rises, the force of expansion of the mercury is sufficient to carry it past the obstacle. When contraction ensues however, the thread of mercury is broken by the projecting piece of enamel or glass, and the mercury recedes from the obstruction into the bulb, leaving the detached thread behind. In use, the stem of the thermometer is inclined downwards, and as a consequence the detached thread takes up its position at the end of the stem away from the bulb. But this does not matter because to read the thermometer it is only necessary to gently tilt the instrument and allow the thread to slide back until it again comes in contact with the obstruction, when the position of the other end of the thread records the maximum temperature. To reset the thermometer the detached thread must be shaken past the glass obstacle in the bore until the space left between the mercury in the bulb and the obstruction is again filled up.



Negretti & Zambra's Maximum Thermometer.



Phillips Maximum Thermometer.

FIG. 13.—Maximum-Thermometers.

Thermometers for recording Underground Temperatures.—It is manifest that for this purpose thermometers must be used which, when drawn out of the borehole, should register the maximum temperature to which they have been subjected. Dunker employed an earth thermometer in the borehole at Sperenberg which Mr. Brough describes in the following words, in a paper he read before the Society of Arts[1] on December 9th, 1896.

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[1] *Journal of Society of Arts*, No. 2299, p. 65.

"The construction of the thermometer is shown in Fig. 14. The stem is open at the top, and bent sideways. It is graduated from the top bent point downwards. Above the point is a small vessel, *e*, open at the top and sealed at the bottom by a little mercury. This, as well as the stem, is surrounded by a glass cover with a side opening, by means of which the thermometer is brought in contact with the external air or water. In order to set the instrument, it is immersed in warm water, so that the mercury flows over from the stem into the sealed vessel *e*. The instrument is then inclined until the point is under mercury, and cooled to a temperature below that expected in the borehole. On lowering the instrument into the borehole, the increased temperature will cause some of the mercury to overflow at the point. Care must be taken to make the observation some time after the cessation of boring, and the thermometer must remain for at least half an hour at the desired depth. Before it is withdrawn, it should be shaken, in order to remove any drops of mercury hanging from the point. When the instrument is drawn up, the glass cover is unscrewed, and the thermometer immersed in water at a lower temperature than that obtaining in the borehole. The temperature of the water is noted by means of a normal thermometer, and, at the same time, the number of degrees that are empty in the earth thermometer are also observed. The sum of the readings of the two thermometers gives the temperature of the borehole at the depth investigated. The reason of this is as follows:—The mercury, when in the borehole, extends to the point; and if the water in which the thermometers are placed is x° cooler than the borehole, the mercury column is x° shorter. These x° must, therefore, be added to the temperature of the water to give the temperature of the borehole."

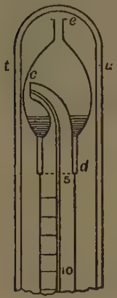

FIG. 14.—Dunker's Earth Thermometer (after Brough).

Negretti and Zambra's Inverted Maximum Thermometer.—This instrument can be used for the same purpose as that just described, and is also a convenient form of thermometer for determining the temperature at any depth in the ocean. The illustration (Fig. 15) shows the plan on which it is constructed. The enlarged drawing (Fig. 16) gives the essential part of the instrument. It consists of an inverted thermometer, in the stem of which there is a contraction of the bore not far removed from the bulb. The thermometer is surrounded by a hermetically sealed glass case, being kept in its position therein by

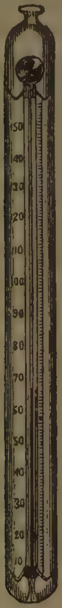

Fig. 15.—Prof. Everett's Form of Negretti and Zambra's Inverted Maximum Thermometer (after Brough).

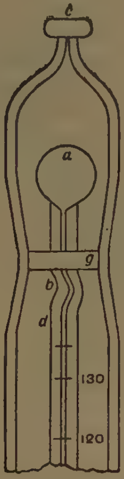

Fig. 16.—Negretti and Zambra's Inverted Maximum Thermometer—enlarged (after Brough).

pieces of cork through which it passes. The instrument is set as follows: the thermometer being arranged with the bulb downwards, it is tapped until all the mercury is in the bulb and the lower part of the stem. It is then placed while in this position in water a little cooler than it is expected the temperature of the borehole or other place will be. After it has assumed the same temperature as the water it is taken out and carefully inverted, when all the mercury on the side of the contraction away from the bulb will run to the other end, which is that from which the graduations are numbered. The top of the mercury column will then record the temperature of the water. Maintaining this position the thermometer is lowered into the borehole or other difficultly accessible place of higher temperature, where the mercury in the bulb will expand and part of it be forced past the contraction. On inclining the instrument this further thread above the contraction joins the column of mercury at the other end of the thermometer, and the end of the united thread measures the temperature in the borehole.

Pyrometers.—These are instruments used for measuring very high temperatures at which mercury thermometers are quite useless. Wedgwood invented a rough and ready plan of doing this by measuring the amount of contraction experienced by a small cylinder of clay after it had been subjected to the high temperature of a furnace. But there is no reliance to be placed upon this form of pyrometer. The most satisfactory pyrometers depend upon the increase in electrical resistance which metallic conductors experience when they are raised to a high temperature. The method adopted by Siemens gives good results. He arranged two coils of the same kind of fine platinum wire of equal electrical resistance. The ends of the coils were connected by long thick copper wires to a distant galvanometer. The resistance of long thick copper wires is negligible compared with that of the coils of fine platinum wire, but the copper wires in connection with each coil are made of equal resistances. One of the coils is then transferred to the place whose temperature is required, while the other is placed in a vessel of water the temperature of which is adjusted until there is no deflection of the galvanometer, when the resistance of both coils is the same and the temperature of the vessel of water is that of the place whose temperature it was required to ascertain. This is a convenient way of ascertaining the temperature at different depths in the ocean.

The Pyroheliometer.—This instrument is intended to measure the amount of radiant energy received by the earth from the sun. It consists, as will be seen by a reference to Fig. 17, of a flat cylindrical silver vessel attached to and in internal connection with a silver tube terminated at the other end by a plate of the same size as the flat vessel. The top surface of the flat cylinder is covered with lamp-black, which, as we have seen, absorbs every kind of radiation received from the sun. The under side of the shallow cylinder and the tube are, on the other hand, brightly polished, that they may radiate as little heat as possible. When not in use the shallow cylinder is covered by a cap. The cylinder is full of mercury, and in it is the bulb of a delicate thermometer, the stem of which is suitably fixed in the silver tube. The instrument is so adjusted that the blackened face of the cylinder receives all the rays from the sun which reach the instrument, and this is ensured when the shadow of the cylinder exactly coincides with the plate at the other end of the tube. The cap is removed and the lamp-black surface left exposed for a known length of time, say or five minutes, after which it is again covered. The instrument is now thoroughly shaken, in order that the mercury may assume the same temperature throughout its mass and the rise of temperature it has experienced is read off from the thermometer. The amount of heat received, which can easily be determined from the mass of mercury and its rise of temperature (p. 42), is corrected for the loss by radiation during the experiment, and enables us to calculate the amount of energy received directly from the sun. Pouillet, the inventor of the pyroheliometer, determined that the amount of heat received from the sun in a year is enough to melt a layer of ice thirty-five yards in thickness stretching all over the earth's surface.

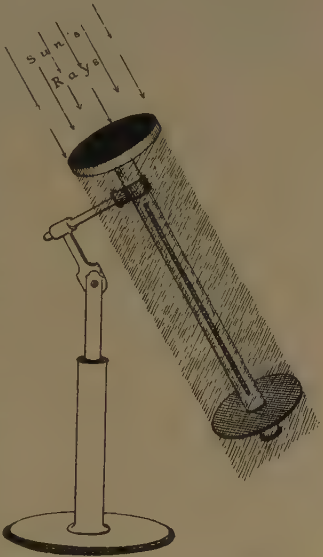

FIG. 17.—A Pyroheliometer.

MEASUREMENTS OF QUANTITIES OF HEAT.

Capacity for Heat.—Since heat is a form of energy and consequently has a mechanical equivalent (p. 25), the reader will understand that we may quite correctly speak of quantities of heat. He should understand, moreover, from his previous reading, that temperature is only a condition of a body which may alter, and does alter, whenever the body comes into contact with something hotter or colder than itself. If, now, we suppose equal masses of different bodies at the same temperature, as for instance water and quicksilver acted upon by the same quantity of heat, we shall find that the temperature of the quicksilver is raised through thirty times as many degrees as that of the water. Or, what is the same thing, the water requires thirty times as much heat to raise its temperature through a given number of degrees as the quicksilver does. This is expressed by saying that the *capacity for heat* of the water is thirty times as great as that of the quicksilver. *The capacity for heat of any body is measured by the quantity of heat necessary to raise a unit mass of it through one degree.*

How Quantities of Heat are measured.—In measuring any quantity we must first decide upon our unit. The unit employed in this case is *the amount of heat required to raise the temperature of one gram of water through one degree.* It is immediately evident that to raise the temperature of two grams of water through one degree will require two units of heat, or to raise the temperature of one gram of water through two degrees will require two units; and always, to find the number of units of heat required to raise the temperature of any quantity of water through any number of degrees, we must multiply the number of units of mass by the number of degrees through which its temperature is raised.

Specific Heat.—When we come to consider the same question in the case of other substances, we are met with the fact that they have differing capacities for heat; and since water has the highest capacity for heat of all known substances, it is clear that no other kind of matter will require so much heat to raise the temperature of unit mass of it through one degree as water does. To find the actual quantity of heat necessary in these cases it is evidently necessary to know how many times less than that of water the capacity for heat of the substance under consideration is. This ratio between the capacities for heat of any other substance and that of water is known as the specific heat of the substance. We may define the *specific heat of a substance as the ratio between the amount of heat necessary to raise the temperature of one gram of it through one degree, compared with the amount required to raise the temperature of the same mass of water through the same range.* Thus, taking the case of quicksilver which we have already noticed, we say :—

$$\text{Specific heat of quicksilver} = \frac{\text{Quantity of heat necessary to raise one gram of quicksilver through one degree}}{\text{Quantity of heat necessary to do same for water}}$$

$$= \frac{1}{30} = \cdot 03\dot{3}.$$

If we represent the capacity for heat of water by 1, the specific heats, or the comparison between the capacities for heat of other substances and water, will always be some fraction less than unity.

Measurement of Specific Heats.—*Method of Mixtures.*—The specific heat of a substance can be determined in many different ways, but it will be sufficient for us, at this stage, to describe that one spoken of as the *method of mixtures.* This plan consists in heating a known quantity of the substance whose specific heat is required to a known high temperature, and, with as little loss of its heat as may be, plunging it into a known mass of water at a known lower temperature, and noticing how many degrees the temperature of the water is raised. From these data the specific heat of the substance can be at once determined.

It is manifest that the substance gives out heat while the water takes it up ; and if there is no loss of heat by conduction or radiation, we can write this fact in the form of an equation, thus :—

$$\begin{array}{c}\text{Number of heat units}\\ \text{given out by the substance}\end{array} = \begin{array}{c}\text{Number of heat units}\\ \text{taken up by the water.}\end{array} \quad . \quad (1)$$

But the number of heat units given out by the substance is found, as we have seen, by finding the product of the number of units of its mass, its specific heat, and the number of degrees through which its temperature falls. Or if we represent these quantities by M, S, and θ, respectively, the number of units of heat given out by the substance will be $MS\theta$.

Again, the number of units of heat taken up by the water is found by multiplying the number of units of its mass by the number of degrees through which its temperature is raised. Or if m equals its mass, and θ_1 its rise in temperature, the number of units of heat taken up by the water is equal to $m\theta_1$.

The original temperature of the substance is, however, known, call it τ: so also is that of the water, say t; as well as the final temperature of the mixture, which we may represent by x. The fall in temperature θ of the substance is therefore equal to $\tau - x$, and the rise in temperature of the water is $x - t$. Instead of $MS\theta$ we may write, then, $Ms(\tau - x)$, and in place of $m\theta_1$ we may write $m(x - t)$, and from equation (1) we know these are equal, provided there is no loss of heat, that is

$$Ms(\tau - x) = m(x - t),$$

from which

$$s = \frac{m(x - t)}{M(\tau - x)}. \qquad \ldots\ldots\ldots (2)$$

This may be expressed in words by saying that the specific heat of a substance can be ascertained by the method of mixtures, and that it is numerically equal to the quotient obtained by dividing the product of the mass of the water into its rise of temperature by the product of the mass of the substance into its fall in temperature.

Experimental Modifications.—The chief objects to be borne in mind in carrying out the above method experimentally are (1) to avoid the loss of heat in transferring the heated substance from the source of heat to the cooler water; (2) to prevent any loss of heat, either by conduction or radiation, from the vessel in which the water must be contained; (3) to ascertain how much of the heat given out by the substance is used up in warming the vessel containing the water, which is called the calorimeter. But for the actual methods adopted to avoid all these difficulties we must refer our reader to books on Heat. The principle of the method is not thereby affected, and this the student has had presented to him.

Example of Method of Mixtures.—Suppose that 30 grams of iron nails at 100° are dropped into 60 grams of water at 13°·2, and the final temperature is found to be 17°·8: what is the specific heat of the nails?

Here our first equation becomes

Number of heat units given out by iron nails	=	Number of heat units taken up by water.

But, number of heat units given out by the iron nails is equal to 30 × sp. ht. (s) of nails × ($100 - 17^{\cdot}8^{\circ}$).

And, number of heat units taken up by the water is equal to

$$60 \times (17^{\circ}{\cdot}8 - 13^{\circ}{\cdot}2)\,;$$

and therefore

$$30 \times s \times 82{\cdot}2 = 60 \times 4{\cdot}6,$$

or

$$s = \frac{60 \times 4{\cdot}6}{30 \times 82{\cdot}2} = \frac{9{\cdot}2}{82{\cdot}2} = 0{\cdot}112.$$

Latent Heat.—The continued addition of heat to a substance results sooner or later in a change of state. If the increase of temperature be continued in a solid it will eventually cause it to melt and assume the liquid condition ; while if a liquid is similarly subjected to continued heating it will at last be converted into a gas. It has been found that to effect such a change of state necessitates the expenditure of a large number of heat units, and that this quantity of heat, moreover, is constant for a given mass of the substance. This amount of heat, which causes a change of state without producing an increase of temperature, is spoken of as *latent heat.* The amount of heat necessary to bring about this change of physical condition is different for different kinds of matter. Thus to change one gram of ice at 0° C. into one gram of water at 0° C. requires 80 units of heat, or, as it is generally expressed, the latent heat of fusion is 80 ; to change one gram of solid lead at a temperature of 326° C. into liquid lead at the same temperature necessitates the expenditure of about 5½ units of heat. Similarly to convert one gram of water at 100° C. into the same mass of steam at 100° C. needs 536 units of heat ; to change one gram of pure alcohol at 78° C. into vapour at the same temperature requires 208 units of heat.

How the Latent Heat of Fusion of Ice is determined.

EXPT. 7.—Weigh out 100 grams of water at about 50° C. into a calorimeter whose weight is known. Pound some ice and dry it ; first on a towel, and then on clean white blotting paper. Having carefully noted the temperature of the water by means of a thermometer which is left in the calorimeter (which we will suppose is at 50° C.) add the ice, little by little, and notice the fall of temperature. When a convenient amount of ice has been added keep the water stirred with the thermometer and watch carefully for the instant when the last piece of ice melts, and at that moment read the thermometer. Call its reading x. Weigh the calorimeter again and find the increase in its weight, which will evidently be the weight of ice added. Let us suppose that 30 grams have been thus put in. These data enable us to determine the latent heat of fusion.

The water gives up heat while the ice receives it, and provided there is no loss by radiation or conduction, the amount of heat received by the ice will exactly equal that given up by the water. More than this, the heat given up by the water does two things—first, it melts the ice, converting it into water at 0° C.; and, secondly, it raises the temperature of the water formed at 0° C. up to x° C. Hence we can write

$$\text{Heat given out by the water} = \text{Heat used in melting the ice} + \text{Heat used in raising the temperature of water formed from } 0^\circ \text{ to } x^\circ \text{ C.}$$

But the heat given out by the water is in our experiment equal to the product $100 \times (50 - x)$; the heat used in melting the ice is equal to 30 times the latent heat of fusion (which we will call l); and that used in raising the temperature of the water formed from 0° to x° is $30\,x$. Our equation therefore becomes

$$100\,(50 - x) = 30\,l + 30\,x,$$

and since we know x from the experiment, it is at once possible to calculate l. If our experiment were successful, it would work out to be 80.

Determination of Latent Heat of Vaporisation.—To find the quantity of heat necessary to convert a gram of water at 100° C. into steam at the same temperature, all we have to do is to pass a known mass of steam at the atmospheric pressure into a known mass of water at the temperature of the air, and notice how many degrees the temperature is raised.

EXPT. 8.—Weigh out about 100 grams of water in the calorimeter whose weight is known. Find its temperature and leave the thermometer in the calorimeter. Now pass steam from an apparatus arranged as in Fig. 18 into the water, and notice that the bubbles condense with considerable noise, causing the temperature of the water to rise. The wide glass tube intercepted in the course of the delivery tube is to entrap any water carried over by the issuing steam. When you are satisfied with the amount of rise in temperature quickly lower the calorimeter, first removing the block shown in the illustration, and record the highest temperature reached by the water after the steam has been passed in. Weigh the calorimeter and water in it again. The increase in weight will be the weight of the steam which has been condensed. Let us suppose that the numbers obtained were as follows :

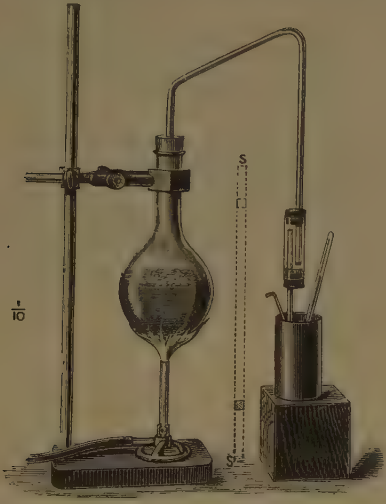

Fig. 18.—Apparatus for Experiment on the Latent Heat of Vaporisation. SS′ represents a screen.

Weight of water in calorimeter	106·6 grams.
Weight of steam condensed	4·1 grams.
Temperature of water before passing in steam	16° C.
Temperature after steam has been condensed	39°·5 C.

Let L be the latent heat of vaporisation, that is the amount of heat necessary to convert 1 gram of water at 100° C. into steam at 100° C. The equation gives the conditions of exchange of heat

Heat given out by the steam = Heat taken up by the water.

But heat given out by the steam consists of two portions : first, that which is evolved by the simple change of 4·1 grams of steam at 100° C.

into water at 100°; and, secondly, that given out by 4·1 grams of water in cooling from 100° to 39°·5. Hence our first equation becomes

$$\begin{array}{c}\text{Heat given out by con-}\\ \text{version of 4·1 grams}\\ \text{of steam into water}\\ \text{at } 100^\circ\end{array} + \begin{array}{c}\text{Heat given out by}\\ \text{4·1 grams of water}\\ \text{in cooling from}\\ 100^\circ\text{ C. down to }39^\circ\!\cdot\!5\end{array} = \begin{array}{c}\text{Heat taken up}\\ \text{by water.}\end{array}$$

or

$$4\cdot1\,\mathrm{L} + 4\cdot1\,(100^\circ - 39^\circ\!\cdot\!5) = 106\cdot6\,(39^\circ\!\cdot\!5 - 16^\circ)$$
$$4\cdot1\,\mathrm{L} + 248 = 2505$$
$$\mathrm{L} = \frac{2257}{4\cdot1} = 550$$

Of course this is quite a rough experiment, with no precautions for the loss of heat by conduction or radiation. Had we adopted careful means to avoid loss of heat as far as possible, our result would work out to be 536. That is, *to convert one gram of water at* 100° C. *into steam at the same temperature requires an expenditure of* 536 *heat units*, or, what is the same thing, when 1 gram of steam at 100° C. is converted into water at 100° C. we have 536 units of heat liberated.

Chief Points of Chapter III.

A Thermometer is an instrument for measuring temperature. Its action usually depends upon the fact that substances expand when heated and contract when cooled.

Maximum and Minimum Thermometers.—As the names imply the former are used for themselves recording the highest temperature recorded during any period, while the latter similarly inform us of the lowest temperature experienced during a given time.

There are several kinds of *maximum* thermometers. In the simplest instrument a small piece of iron wire is pushed along by the expanding mercury column, and left stranded when cooling begins.

In *Phillips's*, the mercury column is broken by a bubble of air, and the detached thread is left in its highest position when the temperature falls.

In *Negretti and Zambra's* an obstruction is introduced just above the bulb. This does not prevent expansion of the mercury thread, but when contraction starts the column is broken by the projection; and the position of the end remote from the bulb, when the other end rests against the obstruction, marks the highest temperature.

Minimum thermometers.—A small capillary tube or dumb-bell shaped marker, while not preventing expansion, is dragged back when contraction ensues, as a result of the adhesion between the alcohol of the thermometer and the marker.

Pyrometers are thermometers for measuring very high temperatures in inaccessible places. An old form of **Wedgwood** is useful in pottery; but the method of **Siemens**, depending upon the increase of electrical resistance with a rise of temperature is the most commonly employed.

The Pyroheliometer is an instrument for recording the intensity of the sun's radiations. It depends upon first absorbing the sun's rays by a lamp-black surface, and then causing them to warm a known mass of water.

Capacity for Heat.—The capacity for heat of any body is measured by the quantity of heat necessary to raise unit mass of it through one degree of temperature.

The Unit Quantity of Heat.—The unit quantity of heat is the amount of heat required to raise the temperature of one gram of water through one degree.

Specific Heat.—The specific heat of a substance is the ratio between the amount of heat necessary to raise the temperature of one gram of it through one degree compared with the amount required to raise the temperature of the same mass of water through the same range.

Method of Finding Specific Heats. *Method of Mixtures.*—A known mass of the substance whose specific heat is required is heated to a known high temperature, and plunged, with as little loss of heat as possible, into a known mass of water at a known lower temperature, and the number of degrees through which the temperature of the water is raised is noted.

Latent Heat.—The amount of heat which causes a change of state without producing an increase of temperature in unit mass of a substance is spoken of as its *latent heat.*

To change one gram of ice at 0° C. into one gram of water at 0° C. requires 80 units of heat; this is usually expressed by saying the *latent heat of fusion* of ice is 80.

To convert one gram of water at 100° C. into the same mass of steam at 100° C. needs 536 units of heat; this number is called the *latent heat of vaporisation* of water.

Determination of Latent Heat of Fusion.—A known mass of pure ice at 0° C. is mixed with a known mass of water at a known temperature. At the moment the last fragment of ice melts the temperature of the water is taken. From these data the latent heat of fusion can be calculated.

Determination of Latent Heat of Vaporisation.—A known mass of steam at 100° C. is bubbled into a known mass of cold water of a known temperature, and the increase in temperature of the water noted. From these data the latent heat of vaporisation can be calculated.

QUESTIONS ON CHAPTER III.

(1) Describe some form of maximum thermometer, carefully pointing out the circumstances under which it is used. Which forms of maximum thermometer are most commonly used?

(2) Give an account of a suitable thermometer for measuring underground temperatures.

(3) For what purpose are pyrometers intended? Describe some form of instrument, and explain the principle of its action.

(4) What does one mean by a body's "capacity for heat"? Explain fully the statement that the capacity for heat of quicksilver is only one-thirtieth that of water.

(5) What is the specific heat of a substance? How would you proceed to determine the specific heat of half-a-crown?

(6) How has the latent heat of fusion of ice been experimentally determined? Give the reasoning by which the constant is determined from the observations made.

(7) For what purposes are maximum and minimum thermometers used?

(8) A minimum thermometer, containing alcohol in which a short index has been introduced, is supported so that the bulb hangs downwards. Will the thermometer now show minimum temperatures? If not, why not?

(9) Why is it necessary to support an ordinary minimum or maximum thermometer in a horizontal position?

(10) 1 lb. of water and 1 lb. of lead are heated to the same temperature, and each is then mixed with 1 lb. of water at the temperature of the room. Which will produce the greatest heating effect, and why?

(11) Why is it that a series of hard frosts must occur before a pond becomes frozen? and why is it that the ice does not melt directly the cold weather ceases?

(12) To be scalded with steam is much worse than to be scalded with boiling water. How do you account for this?

CHAPTER IV

WAVES IN WATER, AIR, AND THE ETHER

Wave Motion.—Waves and wave motion are popularly associated only with water; and the general appearance of a water surface during the propagation of a wave is familiar to everyone. But such wave motion is by no means confined to water. The reader has probably remarked the similarity between water waves and the aspect of a field of standing corn as a gentle breeze passes over it. When the movements of material things around us are carefully examined it is found that motion of the same nature is of very common occurrence. We shall be much assisted in our study of these phenomena if we begin with a very simple example, and one of the best is that used by the late Prof. Tyndall[1] in his Lectures on Sound. Imagine a row of boys standing one behind the other. The boy A at one end of the row will have no neighbour in front of him, while the one, F (say), at the other end will have no boy behind him. Let the boys from F to B place their hands upon the shoulders of the boys severally in front of them. If, now, F is pushed forward, he must evidently push E; let him then resume his upright position. The push which E receives he transmits to D, and then he stands upright. It is clear that this can be carried on until A is reached. A, who also has his hands similarly held out, having no boy in front of him, falls forward—and this as a result of the push imparted to F. Moreover, each boy in turn has gone through similar motions—first moving forward and then regaining his former position. A *wave* has passed along the row of boys. To consider another kind of wave motion, let us imagine a row of material particles connected by elastic bands, and arranged in a straight line as in Fig. 19 (*a*). Suppose, for some reason or other, the particle A moves at right angles to the line of dots. Then, when A has moved to the position A_1, the appearance of the row of particles would be that shown in line (*b*). Let A_1 now start the return journey towards its original position and perform it in the same time as before. Each particle drags the adjacent particle after it, and the continuance of this form of movement on the part of the particles in order, gives rise to the formation of a curve which the student has learnt already to associate with wave motion.

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[1] Tyndall on *Sound*, p. 4.

We can define a wave as "a travelling condition of matter in regard to the position of its particles." Returning to the connected particles, let us suppose that, instead of remaining at rest after it has gone through the movement we have considered, the particle A continues to move at the same rate in the other direction, that is, below the line. A little reasoning will convince our reader that Fig. 19 (*d*) will represent the state of things when the particle A has reached the position A_3—an equal distance below its original position. Finally if A now returns to its initial place, the configuration shown in Fig. 19 (*e*) is obtained.

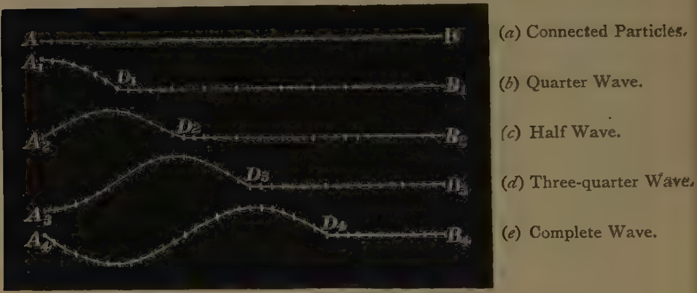

FIG. 19.—Transverse Wave Motion. The distance from A_4 to D_4 is a wave length.

A few terms having reference to wave motion may now conveniently be introduced.

Terms referring to Waves.—A wave similar to that just described is represented in Fig. 20. The various particles *a*, *b*, *c*, &c., were, previous to the passage of the wave-motion, in a row along the horizontal dotted line. The disturbance which gave rise to this wave set the particles in motion, each one moving up and down like a pendulum, and their position at a given instant is shown in the figure. The distance from *a* to *m* is a *wave-length*, that from *a* to *g* is half a wave-length.

The vertical distance between the particles *d* and *j* is called the *amplitude* of the wave. The particles *a* and *m* are said to be in the *same phase* because they are moving in the same direction, while *a* and *g* are in *opposite phases* as they are moving in opposite directions. Further, the "travelling condition" has passed from *a* to *m* in the same time as it has taken the particle *a* to resume its former position. This is a rule of general application. *The wave travels its own length in the same time as that in which any particle completes an entire path.*

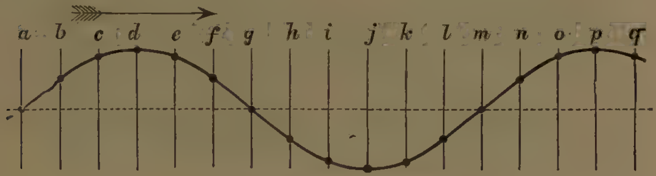

FIG. 20.—A Transverse Wave.

Transverse and Longitudinal Waves.—The foregoing considerations have shown that the direction of the motion of the individual particles does not always bear the same relation to the line of propagation of the wave. Two cases in particular must be noticed. In one case, illustrated by the boys pushing one another (p. 51) the particles move in the same direction as that of the propagation of the wave motion. This is longitudinal wave motion. In the other case the particles themselves move in paths at right angles to the line along which the wave passes, and such a wave is called *transverse*. The difference between longitudinal and transverse waves in regard to the motions of the individual particles is illustrated in Fig. 21.

Transverse waves are illustrated by the following experiments :—

EXPT. 9.—Procure a long piece of india-rubber tubing, such as is used for attaching to Bunsen burners, and fill it with sand so as to make it move more slowly when set in motion. Attach it to a peg on the wall near the ceiling and hold it in the hand by means of the other end. Pull it so that it is extended to its full length without being stretched. Quickly move the hand a short distance to the right and then back to its original position. A wave will be seen to travel along the tubing until it reaches the peg, which is as far as we will consider it in this experiment. The particles of the india-rubber in the neighbourhood of the hand have gone through exactly the kind of movement which the particles on page 52 performed. It is evident that the particles in turn follow the motion of the hand, and that the wave travels along the tubing. Since these directions are at right angles to one another, the wave is a *transverse* one.

EXPT. 10.—Arrange the tubing as in the previous experiment, but instead of moving the hand which holds the free end proceed as follows.

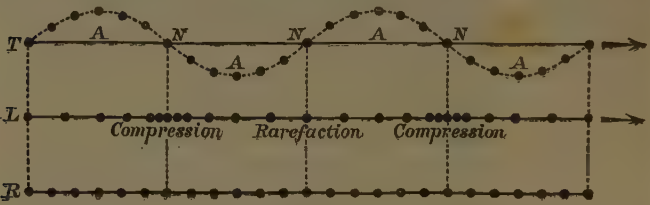

FIG. 21.—Transverse and Longitudinal Waves. *R*, row of particles ; *L*, arrangement of particles ; *T*, arrangement of particles traversed by transverse waves.

Hold the tubing by the left hand ; smartly strike the tubing with the right so that a depression is caused in it, just in front of the left hand. A wave will again pass along the tubing, and as the relation between the two directions of movement is the same as in the preceding case this again is a *transverse* wave.

If the particles move in lines which are parallel to the direction of the wave motion, the wave is spoken of as being *longitudinal.*

The following experiments exemplify this kind of wave motion.

EXPT. 11.—Using a similar piece of tubing to that used in the last experiment, but containing no sand, attach it as before. Holding it in the right hand pull it so that it is at rest and being slightly stretched. Place a clearly seen chalk mark near the end of the tubing attached to the wall. Rub the tubing with the left hand in the direction of its length. Notice the wave which passes up the tubing, and observe that its passage along the upper part is seen by the movement of the chalk mark. The movement of the particles brought about by the rubbing is manifestly parallel to the length of the tubing along which the wave passes, that is we have produced a longitudinal wave.

EXPT. 12.—Wind a metal wire round a cylinder, such as a thick glass tube or a curtain pole. On drawing out the cylinder the wire will be found to form a spiral.[1] Hang the spiral up in the manner shown in Fig. 22. This method of suspension prevents the spiral swinging to the side. Now study the passage of longitudinal waves by carefully pulling the spiral out in the direction of its length and then letting it go. Other ways of utilising the spiral for the generation of longitudinal waves will occur to the student.

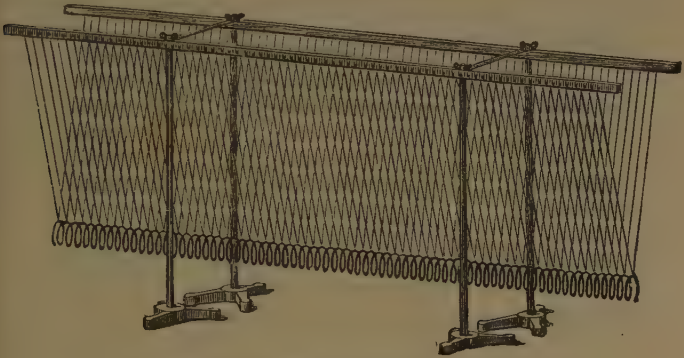

FIG. 22.—Suspended Wire Spiral to show Longitudinal Waves.

Water Waves.—These waves can be best studied by using a long rectangular trough, with glass sides, nearly full of water. The waves can be started in many ways; for instance, the trough can be lifted at one end and at once put down; or, a paddle almost as wide as the trough can be placed in the water a short distance from one end and parallel to it, and then pushed a little way towards the distant end of the trough, being at once brought back to its original position. This will heap the water up immediately in front of the paddle and cause a water wave to travel along the whole length of the trough. On reaching the other end it is reflected, and if we watch the wave narrowly as it comes into contact with the end of the trough it will be noticed that a crest of the wave is reflected as a crest and a depression as a depression (Fig. 23). Moreover, the height to which the water rises on the end of the trough is twice the height of the crest of the wave above the initial level of the water in the trough. That there has been no motion of the water as a whole in the direction of propagation of the wave is manifest from the fact of its being in the trough. To ascertain the nature of the movement of the particles of the water which causes this stationary wave we proceed in another way. Make a wax pellet and load it with a little sand until it just floats in the water. Place it near the side of the vessel and about six inches in front of the paddle. When the paddle is moved in the manner already described the pellet is observed to describe a circular path. The motion of the pellet can be divided into four parts. If in Fig. 23 A the horizontal arrow represents the direction of propagation of the wave the pellet's motion is represented by the circle. The pellet starts from the position A and (1) advances rising, until it occupies the place A′; (2) it continues to advance, but in this second quadrant of its path it begins to fall until (3) on reaching A″ it begins to recede, though as in the previous stage it is still falling ; (4) in the last quarter of its journey it still recedes, but steadily rises until it assumes its original position.

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[1] Mr. D. E. Jones finds that the following dimensions, recommended by Weinhold, are very suitable, viz. :—Diameter of wire, 2 mm.; diameter of spiral, 7 cm.; number of turns, 72; length of completed spiral, 2 metres; length of threads 60 cm.

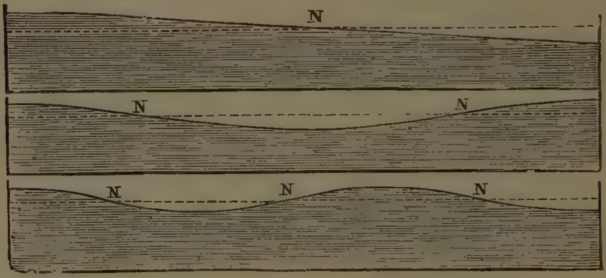

Fig. 23.—Oscillations of Water in a Trough. The Nodes are marked N.

As we have already seen, the wave travels forwards through the water for a distance known as its wave length during the time that it takes any particle of water to go through the complete circular path made up of the four stages we have traced in the case of the pellet. This will be the distance between the top of any one crest to the top of the next, or from the bottom of one depression to the bottom of the next.

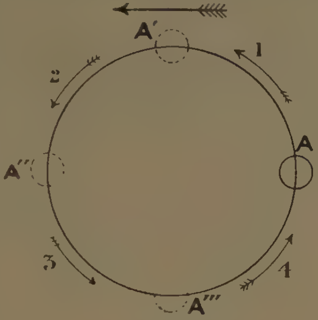

FIG. 23 A.—Motion of a Water Particle in a Wave.

Sound Waves in Air.—These afford one of the most important instances of longitudinal waves met with in nature. They are caused in an infinite variety of ways, but in them all there is some agency at work setting the particles of air into vibration. The exciting cause may be a vibrating string as in the pianoforte, violin, harp, etc. ; or a vibrating reed as in the harmonium, clarionet, oboe, etc. ; or a vibrating membrane as in the drum or tambourine. In all these cases, as well as in those of other musical instruments, the resulting vibration of the air is regular, resulting in the formation of *musical notes*. When the oscillations of the air particles are irregular, that is, not succeeding one another in a definite order at equal intervals of time, we still get sound produced, but of the kind known as *noise*.

Sounding Bodies are in a State of Vibration.—That sounding bodies are in a state of vibration may be easily demonstrated.

EXPT. 13.—Hold the prong of a vibrating tuning fork near the teeth when its vibrations will be felt. Sprinkle some fine sand on a sounding drum or tambourine and notice that some of it dances up and down. Suspend a pith ball near a sounding bell and notice the movements imparted to it by the vibrations of the metal.

Since the air is a material body its particles will be affected in a manner similar to that in the case of the sand grains or the pith ball in the last experiment. They will be set into oscillation. As they exist all round the sounding body a set of spherical waves will be started, precisely as would be the case if we had suspended in the air a hollow ball which alternately expanded and contracted. In this case the expansion of the ball would force the particles of the stratum of air contiguous with the ball outwards, giving rise to a wave of compression, which would pass outwards in all directions through the surrounding atmosphere. This wave of compression would be followed by one of rarefaction as the ball contracted. If this movement on the part of the hollow ball continued regularly, we should have a succession of spherical waves of compression and rarefaction proceeding outwards from the ball. Substitute a vibrating tuning fork for the hollow ball, and exactly the same thing happens. A stretched membrane placed in the path of the waves so formed would be set into vibration by it. The drum of the human ear is such a membrane, and experiences this vibration. Its vibration is conducted by means of a chain of small bones through the inner ear, and the vibrations so conducted are passed on by a beautifully arranged apparatus which we need not describe, until the final ramifications of a nerve from the brain, known as the auditory nerve, take up the vibrations and transmit them to the brain, where we appreciate them as sound.

A Material Medium is Necessary for the Transmission of Sound Waves.—The sound wave is, then, a travelling condition of the particles of a material body, which after passing leaves the body in its original condition. The absence of material particles means the absence of anything to vibrate after the manner we have described, and hence we should expect that sound waves would not pass through a vacuum. Such has been experimentally found to be true. If we arrange a bell under the receiver of an air-pump in such a manner that the bell can be rung after the receiver has been exhausted, we shall find that though the bell can be distinctly heard when the receiver is full of air, yet when we have obtained a good vacuum within the receiver, although we can see the bell going through the movements attendant upon ringing, we can hear no sound from it. Tyndall found that a vacuum sufficiently good could be obtained by first exhausting the receiver in the ordinary manner, and, after filling it with hydrogen, exhausting again. Another precaution which must be adopted is that of suspending the bell by strings and not allowing it to rest on the plate of the pump, which is itself sufficient to transmit the sound waves.

This necessity of a material medium explains why we never hear any of the explosions which are doubtless taking place upon some of the celestial bodies, the atmosphere surrounding the earth is of so limited an extent that there is no material connecting link between the earth and these bodies.

Length of Sound Waves.—The length of an air wave is from one point of greatest compression to the next, or from one point of maximum rarefaction to the next. All air waves are not sound waves. It is only waves which have less [1] than a certain length which can be appreciated by the ear as sound. But there is a limit in the opposite direction. Air waves must also have a certain minimum [2] length before they can be heard. This minimum varies with different persons; some are able to recognise waves as sound waves which are too short to be heard by other people. Certain beasts, such as those of the cat tribe, can, it is found, hear much shorter waves than human beings.

The length of a sound wave determines what is called the *pitch* of the musical note to which it corresponds. The shorter the wave length, or, what is the same thing, the larger the number of waves in a second, the higher the pitch. Notes of a low pitch correspond to sound waves of great length ; while notes of a high pitch are the result of very short sound waves. All sound waves travel with the same velocity, for if this was not so we should be unable to distinguish the tune being played by a distant band—the notes of which the tune is built up, travelling with different velocities, would reach the auditor as a confused noise.

Velocity of Sound Waves.—The velocity of sound waves is found to depend upon the relation existing between the elasticity and the density of the medium through which it is passing.

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[1] Preyer says there must be 16 vibrations a second, which since sound travels about 1,100 feet a second, gives a wave length of 69 feet as the maximum for an audible wave. Helmholtz, however, gives the number of vibrations as 34, corresponding to a length of about 32 feet.

[2] Appunn and Preyer give 40,000 vibrations a second as producing the highest note audible to the human ear, and this corresponds very nearly to a wave length of two-thirds of an inch.

The rule which has been established is that *the velocity of a sound wave varies directly with the square root of the elasticity of the medium and inversely as the square root of its density.* If V = velocity of the sound wave, E = elasticity of the medium (in solids, Young's modulus, see p. 10), D = density of the medium, then we can write

$$\text{Velocity of sound} = \sqrt{\frac{\text{elasticity}}{\text{density}}},$$

or

$$V = \sqrt{\frac{E}{D}}.$$

By the use of this equation it is possible to calculate[1] the velocity of a sound wave in any substance if we know its coefficient of elasticity and its density. And this theoretical value can be checked by experiment.

Direct Experimental Determination of Velocity of Sound Waves.—1. In Air.—The velocity of sound in air has been determined by a large number of independent observers. The most accurate of the direct measurements of this value have been made by French and Dutch physicists, who have taken into account all the disturbing influences which tend to vitiate the result. They allowed for the effect of the wind; they took into consideration the hygrometric state of the air, as well as its temperature and its pressure; all three of which factors influence both the elasticity and density of the air. In the actual experiments the distance between the two stations, the first where the sound was generated and the other where it was received, was measured by accurate trigonometrical methods. Since the time occupied by the passage of light waves over any terrestrial distance can be neglected, because of its extreme smallness, the observer at the receiving station may say that the sound is generated at the first station at the instant he sees the flash of the gun which is the source of the sound. The number of seconds after at which the sound is heard is measured by an accurate chronometer; and knowing the distance between the stations we can at once calculate the velocity in feet per second. The average of a large number of observations gives the result that *sound travels* 1,090

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[1] In applying this equation to the calculation of the velocity of sound waves in air it is necessary to multiply by 1·41, the ratio of the specific heat of a gas at a constant pressure to that at a constant volume. But we must refer the reader to books on Sound for the reasons.

feet per second when the temperature of the air through which it passes is 0° C.

Knowing this result affords us a method of measuring distances which is often very convenient. Thus the distance of a thunder cloud can be estimated by multiplying the number of seconds which elapse between seeing the flash of lightning, and hearing the peal of thunder, by the number which represents the velocity of sound in air. If the thunder is heard some little time after the lightning has been seen, the discharge must have taken place a considerable distance away from the observer. If, on the other hand, the thunder and lightning occur almost at the same time, the thunder cloud is very near.

2. In Water.—The velocity of sound in water was measured in 1827 by MM. Colladon and Sturm by experiments on the Lake of Geneva. They arranged two boats at a measured distance apart. To the first was attached a bell which hung down into the water of the lake. In connection with it was a hammer, so adjusted that when it struck the bell it ignited some gunpowder. The second boat carried a large ear-trumpet arrangement, which similarly passed down into the water and pointed with its open receiver towards the bell. The flashing of the powder gave the instant the sound wave started. The moment the sound was heard by an ear applied to the other end of the trumpet was that at which the sound wave completed the measured distance. The result obtained showed that the water of the Lake of Geneva, when at a temperature of 8° C., conducted sound at the rate of 4,708 feet per second.

3. In Solids.—Sound is as a rule transmitted at a much greater rate by solids than by either liquids or gases. The ratio between the square roots of the elasticity and density in their case is much greater. The actual velocity in different solids varies between very wide limits. While the velocity of sound in lead is rather less than in water, its velocity in iron is nearly four times as great. Direct measurements of the velocity in solids have only been made in a few instances. Biot experimented with the iron water-pipes of Paris and found the velocity of sound through them to be about 10,833 feet per second, or nearly ten times as great as through air at the same temperature. The greater ease with which solids transmit sound waves is a matter of common observation. Most people have noticed that an observer at a distance can always distinguish two reports of a blasting operation. The first is received through the earth, the second, later one, through the air.

Indirect Determination of Velocity of Sound in Air.

EXPT. 14 (Fig. 24).—Nearly fill a tall cylinder with water and put into it a wide glass tube, open at both ends, and have a wooden universal joint near to clamp the tube in any position. Select a tuning fork whose vibration number is known, and sound it either by bowing the prongs or by striking it on the table. Hold the sounding fork above the tube and raise or lower the tube in the water until the position at which the tube resounds or resonates most loudly is discovered. Clamp the tube in this position and carefully measure the distance from the level of the water to the open end of the tube. From these data we can calculate the velocity of sound in air, at the temperature of the room.

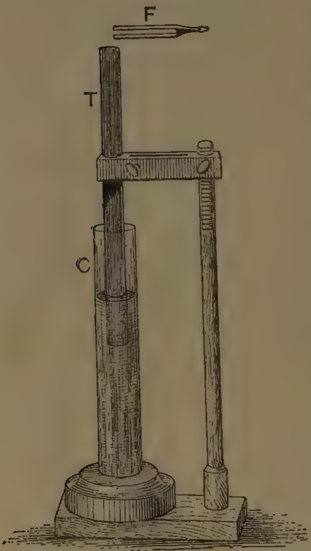

FIG. 24.—Experiment to Determine the Velocity of Sound in Air.

The reader already knows that the velocity of sound in a second is equal to the number of waves or vibrations in that time multiplied by the length of one wave—

Velocity per second = number of vibrations × wave length.

As we know the number of waves the tuning fork gives rise to in one second, or its vibration number, all we further require is the length of the waves. This can be obtained by multiplying the length of the tube above the liquid by four. It can be shown that a closed pipe, *i.e.*, one closed at one end, when sounding as in our experiment, vibrates in such a manner that the length of the sound wave to which it gives rise is four times the length of the tube.[1]

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[1] Readers should consult a book on Sound, e.g. *Elementary Lessons on Sound.* Stone, p. 40.

Waves in the Ether.—We have defined a wave as a travelling condition of matter in regard to the position of its particles, hence the first question which presents itself when we come to a consideration of ether waves is—What is the nature of this ether, the motion of whose particles produces waves, which variously become known to us as Light, Radiant Heat, etc.? In answering such a question it must be insisted upon that the existence of such a medium as the ether cannot at present be directly demonstrated. It differs from ordinary matter in being unable to affect our senses. We cannot feel, smell, see, hear, or taste it. Yet we are almost certain of its existence. If we start with the assumption that a medium exists which is capable of transmitting energy in the form of wave motion, and is therefore possessed of density and elasticity, and that it pervades all space and permeates all transparent bodies and cannot at present be removed by any sort of air-pump, we are able to explain satisfactorily all the observed phenomena connected with the study of Light, Radiant Heat, etc. And since we are able, moreover, to predict from time to time what ought to happen under certain circumstances, and find our predictions turn out to be true, the evidence in favour of the truth of the hypothesis becomes very strong. For reasons of this kind physicists of the present day believe in the existence of *the ether*, or the *luminiferous ether*, as it is sometimes called. The ether exists in what we ordinarily call a vacuum, no matter how perfect it may be. It is present in air, glass, and all transparent bodies. In opaque bodies it has at least lost the power of transmitting light waves, though in some cases (p. 66) it will transmit dark heat waves. The ether, too, must undergo some change in transparent bodies because light waves of different lengths are transmitted with unequal velocities, which is quite contrary to what we have noticed in the case of sound waves in air.

The reasons for the existence of the ether are further strengthened by the fact that the phenomena of electrical attraction and repulsion, current electricity, and magnetism are all best explained as different well-marked conditions of such a medium; but for information on this point we would refer our reader to other books.[1]

Ether Waves.—Ether waves are transverse waves, and are hence unlike sound waves, which are longitudinal. They are, compared with audible air waves, extremely short, as we shall see later. But they differ in length between very wide limits. The shortest ether waves, or, using the language employed in speaking of sound waves, the ether waves of highest pitch, do not affect the retina of the eye. They have no power of giving rise to the sensation of light, but they are very active chemically. They are known as Invisible, Chemical, Actinic, or *Ultra-Violet* waves. The last name is to mark the fact that they are shorter than the shortest visible waves which give rise to the sensation of violet. As the length of the waves is increased the waves become visible, giving rise to sensations of the colours of the spectrum in order from violet to red (Fig. 25). The visible spectrum is thus a gamut of colour, and the individual colours are analogous to musical notes. There is no line of demarcation between one colour of the spectrum and the next; and the only satisfactory method of speaking of any particular part of the spectrum is to refer to the wave length corresponding to the part it is wished to indicate. There are well-defined waves longer than those corresponding to the extreme red end of the visible spectrum whose presence can be easily demonstrated by means of a thermopile and galvanometer. These long invisible rays are known as the dark heat waves, because their

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[1] See *Modern Views of Electricity*. Lodge.

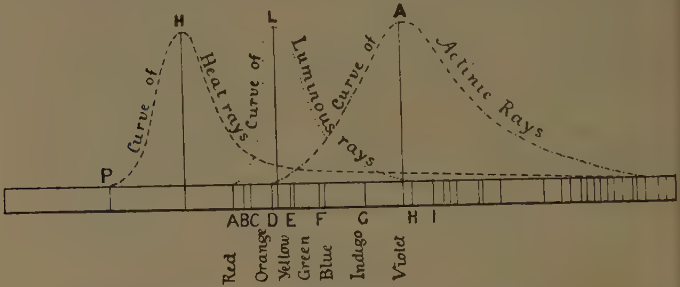

FIG. 25.—Curves of Thermal, Luminous, and Chemical Intensities in the Solar Spectrum. The greatest heating effect is shown to be produced by waves below the red end of the Spectrum, and the greatest chemical effect by waves just beyond the violet.

power of warming bodies by which they are absorbed is their chief feature. These long waves are also spoken of as the *Infra-Red* part of the spectrum, because their frequency or pitch is below that of the visible red portion.

Properties of the Spectrum—Thermal Effect.—When ether waves fall upon material bodies the effects are very various in the case of different substances. As the student has learnt they may be absorbed by the material body and warm it, when the waves are referred to as Radiant Heat; should the wave motion be absorbed by the retina and cause the sensation of colour, the waves are referred to as Light; while if they cause chemical changes in a photographic plate or a green leaf they are known as Chemical Rays. But ether waves of all lengths can give rise to heat in a body by which they have been absorbed. Lamp-black is a substance which is capable of absorbing ether-waves of all lengths. Yet all waves have not this power to the same extent, nor does it appear to be proportional to the wave length.

Tyndall showed that in the case of light from the electric arc passed through a rock-salt prism, those waves whose position in the spectrum was about as far from the visible red as the latter was from the green produced the maximum heating effect. Moreover, there is a gradual increase in the thermal effect from the violet to the red of the visible spectrum, which increase is rapidly augmented from this point to the region of maximum effect already mentioned. The point of greatest heating having been reached, there is a rapid diminution of the effect until a wave length twice as far into the infra-red portion of the spectrum as the position of the maximum result is reached. After this there is a very gradual diminution in the effect.

Illuminating Effect.—Very little need here be said under this heading. Fraunhofer and Herschel have shown that waves of the lengths corresponding to the yellow part of the spectrum have the greatest illuminating effect, while those giving rise to the sensation of violet have the least.

Chemical Effect.—Waves of all lengths can, under suitable conditions, be made to produce a chemical effect. The dark heat waves can be made to cause the decomposition of certain complex molecules. Ordinary sunlight can bring about the direct combination of some chemical elements, as, for instance, hydrogen and chlorine. But the two classes of effects, viz., those which constitute photography and the decompositions effected by chlorophyll, are of chief importance.

We must assume the reader is already familiar with the latter, and can only refer in the briefest manner to the former. Some chemical compounds, among which we may mention silver chloride, are blackened by light; and it has been found that this blackening is most intense in the violet portion of the visible spectrum, though the intensity is very little diminished for some considerable distance into the ultra-violet portion. It has also been established that waves of some lengths are most active in starting chemical actions, while others are very powerful in the direction of maintaining reactions which have commenced. Becquerel has named the former *exciting* waves, and the latter *continuing* waves.

Absorption of Ether Waves.—A lamp-black surface can, as we have seen, absorb ether waves of all wave lengths. But most substances exert a selective absorption. The experiment of Tyndall which we have described (p. 65) would, therefore, give different results if prisms of other materials than rock-salt were used. Had a water prism been employed the maximum thermal effect would have been found situated in the yellow, with a crown-glass prism it would be in the red; but rock-salt, since it allows all waves to pass with equal facility, absorbing practically none of them, gives an unmodified spectrum. A solution of iodine in carbon bi-sulphide is opaque to all light waves, but allows the dark heat waves to pass without much absorption. A solution of alum in water absorbs all the ether waves emitted by a body heated below incandescence. Kirchoff made what is perhaps the most important discovery affecting this question of absorption. He found that a flame coloured by sodium was capable of absorbing just those wave lengths which incandescent sodium vapour emitted. The effect of this absorption by such a flame is very important. If compound light, from say an electric light or a lime light, is passed through such a flame there is found to be a dark line at the part of the spectrum which corresponds to the wave length of the radiations emitted by incandescent sodium vapour. Similar results are caused by the passage of white light through the vapours of other metals—the spectrum is always traversed by dark lines in those positions where bright lines should have occurred if the radiations from the incandescent vapours themselves had been subjected to dispersion by a prism. Such spectra containing dark lines caused in this way are called ***absorption*** spectra.

EXPT. 15.—Arrange a spectroscope to observe the spectrum of sodium given by burning common salt in a spirit-lamp. Only a yellow line, or if the spectroscope is a good one, two yellow lines very close together will be seen. Place a limelight in front of the slit of the spectroscope, and while observing the bright sodium lines start the light. Instead of the bright lines, dark lines will be seen in exactly the same position across a continuous band of colour.

Absorption of Radiant Energy by the Atmosphere.—It has been found that the infra-red part of the spectrum of sunlight is not so intense as that of the electric light, and it has been demonstrated that this is owing to the absorptive power of the aqueous vapour of the atmosphere. Aqueous vapour, just like water (p. 66), absorbs the dark heat waves. Tyndall, from whose experiments most that is at present known was learnt, filled an experimental tube with dry air and measured its absorption. On exhausting the tube and filling it with ordinary air, which of course contained an amount of water vapour depending upon the temperature of the air and other circumstances, he found the amount of absorption was 72 times as much. Direct experiments on Mont Blanc show what an important part the aqueous vapour in the atmosphere plays in regulating the amount of heat received from the sun. He estimated that the intensity of the sun's heat on the top of Mont Blanc compared with that at Geneva was as 6 to 5. Moreover, it has also been demonstrated that the amount of absorption is most on those days when there is most aqueous vapour in the air.

Not only are the dark heat waves thus absorbed by the atmosphere, but also some of those waves which by their impact with the retina cause the sensation of light. It is a matter of common observation that the light from the sun at the times of sunrise and sunset is decidedly red in its character. At these times, as the reader knows, the light has to pass through a greater thickness of atmosphere than at noon, and it would seem that the waves between the violet and the red are more diffused and absorbed than the red waves themselves (*see* p. 83).

The same appearance is noticed when the sun is viewed through a thick mist.

As the altitude of the sun is increased, and the thickness ot atmosphere is correspondingly diminished, the colour of the light approaches, and at last assumes, the ordinary character of sunlight.

Velocity of Ether Waves.—The velocity of propagation of waves in the ether has been determined in many ways. We can only afford space to refer to a few of them.

1. *By Observations on Jupiter's Satellites.*—Jupiter has five moons which complete their journeys round their planet in different times, but in every case in a much shorter period than that taken by our satellite. Further, they revolve round Jupiter in a plane nearly coincident with that of the planet's orbit round the sun, and consequently scarcely a day goes by without one or other of these moons passing into the shadow of the planet thrown by the sun, and so becoming invisible to us. The time at which the disappearance of the moon will take place can be calculated exactly for months or years in advance; and were the earth at rest in relation to the sun, no complication would arise. If, now, when the earth and Jupiter are on the same side of the sun, we observe the time of disappearance of one of the moons into the planet's shadow, and then calculate the time at which the phenomenon should happen six months hence, we find when the half-year has elapsed that the observed time of disappearance and the calculated time do not agree. It occurs at about 16′ 30″ later. This is because the earth's position relatively to Jupiter has undergone a change;

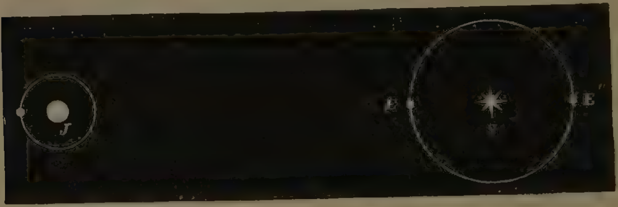

Fig. 26.—To Explain Determination of Velocity of Light by Jupiter's Satellites.

it is now on the other side of its elliptical orbit, and the light from the vanishing moon has to travel across the orbit before reaching us and this extra journey is performed in the time stated. Knowing the distance across the earth's orbit Roemer calculated the velocity of light to be about 190,000 miles per second. This value for the velocity is not a very correct one, because the distance across the orbit was not very accurately known.

2. *By Aberration Phenomena.*—An astronomer who wishes to view a star in the zenith through his telescope finds that he must incline his instrument at an angle which depends upon the relative velocity of light and that of the earth on its orbit. Figure 27 will make this clear. Let S be the position of the star, and Sa the direction in which the light travels from it to the earth. While the light is completing this journey the earth is carried round on its orbit through a distance aE, and consequently an observer in the position a when the light started from the star will have been carried to E by the time the light reaches the earth. Applying the parallelogram of velocities we know the light will appear to come along the line S′a, and the observer must slope his telescope along this line to see the star. The angle S′aS is known as the *constant of aberration.* Its value is very small being only 20·6 seconds of arc. Knowing the distance through which the earth is carried and the constant of aberration, it is easy to calculate the distance travelled by the light in a second. The value works out to be about 186,000 miles per second.

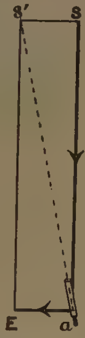

FIG. 27.—The Aberration of Light.

The Aberration of Light is more fully dealt with in Chapter XIII.

3. *By Terrestrial Experiments.*—The velocity of light has been determined by various experimenters on the earth itself. We can only describe the principle of the method employed by M. Fizeau in 1849 (Fig. 28). Two places about five miles apart were chosen and light sent from one station was reflected back to its starting point by a mirror which it struck normally

at the more distant station. There was then interposed between the mirror and the source of light a toothed wheel, carefully constructed so that the width of the teeth and spaces between them were equal. This was placed near the source of light. It is clear that if the reflected light is received by a tooth of the wheel it will not reach an eye suitably placed on the same side of the wheel as the source of light. Moreover, if the wheel be rotated it can be given such a speed that there is always a tooth in the way to meet the light which has travelled to the mirror and back again. Similarly the speed can be made of such a value that one of the spaces shall always fall in the path of light. When this is the condition of things it is easy to see that the wheel rotates through an angular distance equal to the width of a tooth in a time that the light travels from the wheel to the mirror and back again to the wheel. The time occupied by the wheel in rotating the angular distance can be at once calculated from the rate of rotation, while the distance from the wheel to the mirror can be directly measured.

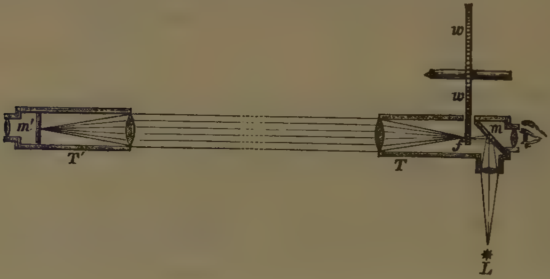

FIG. 28.—Fizeau's Apparatus for Determining Velocity of Light. *L*, source of light; *w*, *w*, toothed wheel; *m*, plain glass mirror; *m'*, silvered mirror; *f*, place where the light strikes the toothed wheel.

CHIEF POINTS OF CHAPTER IV.

Waves.—A *wave* has been defined as "a travelling condition of matter in regard to its particles."

A *wave length* is the distance through which a wave travels in the time necessary to complete a vibration. In a water wave it is the distance from one crest to the next, or from one depression to the next.

The *amplitude* of a wave is the distance swung through by any one of the particles of the medium which the wave traverses. Particles moving in the same direction are said to be in the *same phase*, those moving in opposite directions are in *opposite phases*.

Transverse and Longitudinal Waves.—Waves in which the particles themselves move at right angles to the line along which the wave passes are said to be *transverse*; those in which the particles move in the same direction as that in which the wave passes are *longitudinal*.

Sound Waves in air afford examples of longitudinal waves. They are made up of compressions and rarefactions arranged alternately, which, emanating from the sounding body in all directions, cause the wave to be *spherical* in form.

Musical notes are the result of *regular* vibrations of the air affecting the auditory nerve. When the vibrations are *irregular* a *noise* is caused.

A material medium is necessary for the transmission of sound waves, and consequently no sound is heard from a musical instrument vibrating *in vacuo*. All air waves are not sound waves. No wave longer than 32 feet (Helmholtz) nor shorter than two-thirds of an inch (Appunn and Preyer) can be appreciated as sound by the human ear.

The shorter the wave length, or, what is the same thing, the greater the number of vibrations in a second, the higher the *pitch* of a musical note, and *vice versa*.

The *velocity of a sound wave* in any medium varies directly with the square root of the elasticity of the medium, and inversely as the square root of its density, which law may be expressed by the equation—

$$V = \sqrt{\frac{E}{D}}$$

The *velocity of sound waves in air* at a temperature of 0° C. is 1,090 feet per second. This was determined by noting the time between seeing the flash and hearing the report of the discharge of a cannon at a measured distance away.

The *velocity of sound waves in water* at 8° C. is 4,708 feet per second. This result was obtained by Colladon and Sturm from experiments in the Lake of Geneva. Sound waves travel through iron at the rate of 10,833 feet per second (Biot).

The velocity of sound in air can be *indirectly* determined by ascertaining the length of a column of air which resounds to a vibrating tuning-fork of known pitch (Expt. 14). The length of the column of air is one quarter of the wave length of the note.

$$\begin{aligned}\text{Velocity of sound per second in air} &= \text{number of vibrations} \times \text{wave length}\\ &= \text{number of vibrations} \times \text{four times length of air column.}\end{aligned}$$

Ether Waves are transverse vibrations of the *luminiferous ether*.

According to their length they are variously known, beginning with the shortest, as *actinic* or *ultra-violet* rays, *light* rays, and *radiant heat* rays. Only waves within certain limits affect the retina and become known as light; those which are too short to do this are the ultra-violet, those which are too long are the *infra-red* rays. The radiations from the sun are collectively known as *sunlight.* This can be decomposed by a prism to form a *spectrum.* The *thermal effect* of the spectrum is most intense at the region as far removed from the visible red as the latter is from the green. The greatest *illuminating effect* is found in the yellow part of the spectrum. The maximum chemical effect is a property of the violet end of the spectrum.

Ether waves are variously *absorbed* by different substances. Lamp-black absorbs waves of all lengths, but most substances exert a selective absorption; thus a solution of iodine in carbon bisulphide absorbs all light waves, but transmits the infra-red part of the spectrum. The aqueous vapour of the atmosphere absorbs these *dark-heat* rays.

The *velocity of ether waves*, or, as is more commonly said, the velocity of light, can be determined in at least three ways:

(1) By observations of Jupiter's satellites.
(2) From aberration phenomena.
(3) By terrestrial experiments.

QUESTIONS ON CHAPTER IV.

(1) Compare the vibrations which produce sound and light respectively, stating in what respects they agree, and in what respects they differ.

(2) Describe the nature of the movements of waves in water, sound waves in air, and radiation waves in ether.

(3) Describe one method by which the velocity of light has been determined.

(4) How can the velocity of sound be determined by an experiment with a tuning-fork of known pitch, and a glass cylinder into which water can be poured?

(5) Distinguish between transverse and longitudinal waves.

(6) Explain the following terms applied to waves:—Wave length, amplitude, phase.

(7) How can it be shown that a material medium is required for the transmission of sound?

(8) Tremendous explosions occur upon the sun, but we cannot hear any sound produced, though we can see the effects of the explosions. How do you account for this?

(9) Upon a certain occasion thunder was heard two seconds after a bright flash of lightning had been seen. What was approximately the distance of the thunder-cloud from the place of observation?

(10) Light consists of vibrations in a medium called the ether. Write a short essay in support of this statement.

(11) Describe an experiment to illustrate the absorption of ether waves.

(12) Why is it that the so-called dark room of a photographer is only lighted with ruby-coloured glass?

(13) How can it be proved that ether waves exist which do not affect the sense of sight?

CHAPTER V

THE ATMOSPHERE AND ATMOSPHERIC MOVEMENTS

Recapitulatory.—Our reader has previously learnt to regard the atmosphere as a gaseous envelope completely covering the earth, which being material has weight, and everywhere exerts pressure upon the surface of the earth. This pressure equals 15 lbs. on the square inch, and is measured by the barometer, in which instrument it balances a column of mercury whose height varies as the weight of the atmosphere alters from time to time. Being a gas the atmosphere obeys Boyle's law, which states that when the temperature remains constant, the volume of a gas varies inversely as the pressure to which it is subjected. Consequently, if a cubic foot of air at the sea level, where the pressure is 15 lbs. on the square inch, were taken up to a height of 3½ miles, where the pressure is one-half or 7½ lbs. on the square inch, it would expand to 2 cubic feet. When the atmosphere becomes warm and moist its weight per unit volume becomes less, and the height of the barometer falls. When, on the other hand, the air is cold and dry, it becomes heavier and the barometer's height rises.

Moreover the atmosphere is a mixture of gases in which the constituents are very intimately mixed, resulting in a remarkable uniformity in its composition throughout its whole mass. This uniform composition is a direct result of the power of diffusion possessed by gases, which causes the molecules of which they are built up to separate as far as possible from one another. The chief gases present in the air are nitrogen and oxygen. There are nearly twenty-one parts of oxygen and seventy-nine of nitrogen in one hundred parts by volume of air. But other substances are present in varying proportions, such as water vapour, carbon dioxide, ammonia, ozone, argon, sulphur dioxide, and dust particles. The composition of the atmosphere is being persistently modified by the respiration of animals and as regularly readjusted by plants. Animals during life never cease to breathe in oxygen and to breathe out carbon dioxide. Plants just as regularly decompose this gas expired by animals, retaining its carbon and setting the oxygen free. There is consequently a never-ceasing flux, which under no circumstances, however, results in a permanent change in the composition of the atmosphere.

This gaseous envelope is warmed by the solar radiations, part of which is absorbed in its passage through the atmosphere and converted into heat, while the remainder goes to warm the earth, which in its turn heats the air in contact with it, as well as radiates dark heat rays which are absorbed by the water vapour of the atmosphere. As we ascend into the atmosphere it is found to become colder because the air higher up is above the general level of the earth, and therefore does not receive much heat by contact; and further the air is rarefied, and there is not so much above us to prevent the escape of heat radiated from the earth.

REFRACTION EFFECTS OF THE ATMOSPHERE.

Twilight.—In this chapter we have to describe in greater detail some of the phenomena which have been already introduced to the student. It will be remembered that a wave of light or other radiation is refracted when it passes from a medium of less into one of greater density and *vice versa*. In the former case the ray is bent towards, and in the latter from, the normal drawn at the point of incidence.

One of the direct consequences of these facts in the case of the atmosphere, which consists of concentrically arranged layers of decreasing density outwards, is that we have *twilight* occurring both before sunrise and after sunset. The explanation of this is at once apparent from an inspection of Fig. 29, where A represents the position of an observer at sunrise. To such a person the sun appears in the position S′ when in reality it is below the horizon at S. The rays travelling from the sun proceed in straight lines, until, coming into the atmosphere, they are bent more and more towards the normal as the density of the air increases. This continued increase in the extent of refraction results in the assumption of a curved path for the ray of light within the confines of the atmosphere, and to our observer the sun appears to be in the direction along the tangent to the curve at A, or to have already risen when still below the horizon.

Similarly at B, where we have the position of the observer at sunset represented. The final result is that the sun is still visible after the setting has been actually accomplished. The ray which is shown in the figure travelling from the sun S, below the horizon to the person at B, experiences a refraction ot a precisely similar kind to that described at sunrise, and the tangent to its curved path being in the direction BS″ makes it appear to the observer at B that the sun is in the position S″. Moreover, even after the sun is no longer visible at the time of sunset and before it is actually on view at sunrise, as the reader very well knows, rays of light coming into contact with the outer parts of the atmosphere are diffused by it, and, though incapable of actually producing an image of the sun, give rise to what we call twilight. The greater the thickness of atmosphere through

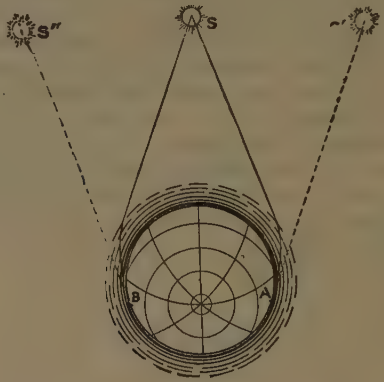

FIG. 29.—To explain Twilight Phenomena.

which the light has to pass at the time of sunrise or sunset, the longer will the twilight last.

Mirage.—Not only is the density of the air affected by an increase of pressure, but also, though in a contrary manner, by an increase of temperature. An exalted temperature is accompanied by expansion, and a consequent diminution of density which is most marked where the expansion is greatest. Consequently in hot countries where the land gets very hot during the day, the air in immediate contact with it is heated and expands, causing the density to become less—the final result being that in such a locality the density increases outwards. The illustration Fig. 30 will explain how such a condition of things may result in the formation of the *mirage*. The horizontal lines which are drawn above the surface of the earth in the illustration represent layers of air of increasing density. M is some elevated object from which a ray of light Ma reaches the zones of variable density, and at a is refracted rom the normal ; on passing into a medium of less density, the same thing happens at d. At A, however, the angle at which the ray meets the next stratum is so obtuse that instead of entering the stratum it is totally reflected along the line Ad'. This reflected ray entering a stratum of increasing density at d' is bent towards the perpendicular and so on at a'. Finally the ray may enter an eye Q, and to it appears to have come along the line

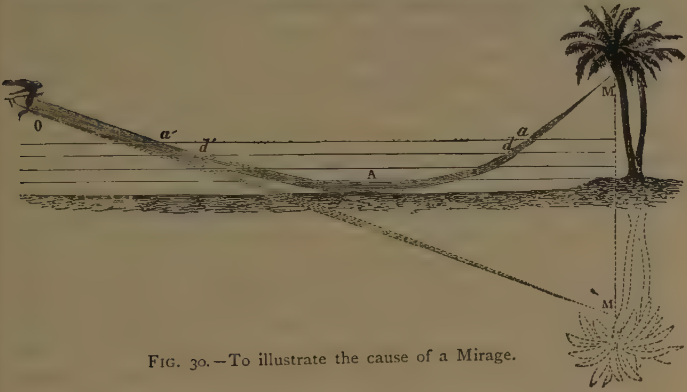

FIG. 30.—To illustrate the cause of a Mirage.

OM′, in which direction we shall have an image of objects at M formed.

Such a condition of things as this often obtains in hot countries like Egypt, where the ground may have the appearance of a sheet of water in which neighbouring trees or villages are reflected. A somewhat similar phenomenon sometimes takes place at sea, resulting in inverted images in the air of ships below the horizon. The place of greatest density is in this case, though, near the water. The direction of the rays from the ship is modified in the manner already described for those from the sun in explaining twilight, and we must refer the reader to Fig. 29 for the explanation of the occurrence.

Twinkling of Stars.—The twinkling of stars is indirectly due to the refraction of the atmosphere. The stars are so far away that they may be regarded merely as so many luminous points. The rays of light which reach us from any one of them traverse slightly unequal distances, in consequence of the differing amounts of refraction they undergo in their passage through the atmosphere. The result is that their phases (p. 53) on entering the eye are not the same, and they interfere with one another, causing first light of one wave length and then that of another to be extinguished. The eye is of course conscious only of those constituents of the white light which are not extinguished, which part is said to be complementary to those extinguished. The wave lengths blotted out vary from time to time, and consequently the parts perceived also vary, causing twinkling, but the effects are not identical in the eyes of different observers.

ABSORPTION AND DIFFUSION.

Absorption of Dark Radiation by the Atmosphere.—The rays from the sun are much diffused in passing through the atmosphere, the amount of diffusion depending upon the lengths of the ether waves; they are also absorbed to a slight extent. This selective absorption differs from the selective action of diffusion in the fact that it is not exerted by the chief mass of the air, but in a high degree by aqueous vapour and carbon dioxide, which are present in the air in small quantities.[1] The absorption is chiefly limited to long waves such as are radiated from the earth, the luminous rays being almost unaffected. Indeed, though the influence of the absorption is comparatively small upon the light and heat of the sun, it must be of great importance in the case of rays from the earth. It is doubtful whether aqueous vapour or carbon dioxide plays the more important part in this absorption. Both are found to be very effective, so that probably sometimes the one and sometimes the other may have the greater effect, according to the proportion of each in the air.

Tyndall,[2] in a series of careful and exhaustive experiments, in which every disturbing influence was allowed for, has shown that air with aqueous vapour in it is nearly one hundred times more absorptive of dark heat rays than pure dry air. Tyndall, in speaking on this point, said in one of his discourses, "No doubt can exist of the extraordinary opacity of this substance to the rays of obscure heat; particularly such rays as are emitted by the earth after being warmed by the sun. Aqueous vapour is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air which overspreads this country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost. The aqueous vapour constitutes a local dam, by which the temperature of the earth's surface is deepened: the dam, however, finally overflows, and we give to space all that we receive from the sun."[3]

Some of the consequences, both direct and indirect, of the absorptive influence of this aqueous vapour are of the greatest interest. Among the former we include those which result from an absence of water vapour in the air, which are of the kind described in the above quotation. A realisation of such conditions occurs on the moon, where there is no watery envelope to prevent the radiation of heat from the satellite, and consequently there the difference between the highest temperature of the lunar day and the lowest temperature of the lunar night must be immensely great.

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[1] A full discussion of the action of water vapour and carbon dioxide in diffusing and absorbing radiation will be found in the *Philosophical Magazine*, May 1896.

[2] The student should read *Heat Considered as a Mode of Motion*. Tyndall. Chapter XI.

[3] *Ibid.*, 2nd edition, p. 403.

An approximation to this condition of things occurs at various places on the earth's surface. The winters of Tibet, for instance, are, from the absence of water vapour in the air and consequent excessive radiation, exceedingly rigorous. Over the desert of Sahara, too, the air is exceedingly dry, and the days are intensely hot, followed by exceedingly cold nights. After sunset, since there is no water vapour to prevent a free radiation of heat, the temperature of the earth rapidly falls, often reaching the freezing point. The same thing is true of the central parts of Australia. By indirect consequences we mean the results attendant upon a corollary to the statement of the great absorptive power of water vapour, viz., that like all good absorbers aqueous vapour radiates heat very easily. The "zone of constant precipitation"[1] is partly to be explained, according to Tyndall, as a result of the last-mentioned property of aqueous vapour. In addition to the cooling of the water vapour, formed in such enormous quantities in equatorial regions by evaporation from the ocean, by its ascent into higher regions, the radiation from the vapour itself must also be taken into account, inasmuch as it is eventually instrumental in a further cooling of the vapour. At first the radiation which takes place is intercepted by the aqueous vapour in the air surrounding the ascending current. But the amount of this vapour in the air gets rapidly less as the earth is left behind, and after a time radiation takes place from the ascending current quite freely into a space almost devoid of any absorptive power, with the result that great cooling ensues and a consequent rapid condensation, which we thus see is in reality brought about by a combination of causes.

The cumulus clouds of our own latitudes, too, are probably formed in a similar way. Finally, the low temperatures near the summits of mountains are brought about in the same manner.

Action of Dust and Fine Particles.—Mr. Aitkin[2] has shown that not only does fine dust occur in the air of inhabited countries, over the water surfaces immediately adjoining them, and up to an altitude of 6,000 or 7,000 feet among the Alps of Switzerland, but also in the air over the open ocean so far away from any land as to preclude the possibility of artificial pollution. Its existence has been directly demonstrated also at a height of more than 13,000 feet.

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[1] *Physiography for Beginners*, p. 226.

[2] Mr. Aitkin's papers on the connection between dust and meteorological phenomena will be found in the publications of the *Roy. Soc. Edin.* from 1888 onwards, and some also in *Nature.* For some of the information we are also indebted to a paper by R. D. Friedlander, *Quart. Jour. Roy. Met. Soc.*, July 1896.

As a rule the quantity of dust decreases as the wind increases, or when calms occur dust accumulates. Moreover, it has been fairly established that in a calm atmosphere the amount of dust decreases with the altitude.

The results produced by atmospheric dust are very various, and some of them have been previously described. In addition, there is evidence that fine particles cause the condensation of moisture before the air is saturated. Again, since the presence of dust increases the radiating power of the atmosphere, it increases its rate of cooling, causing the formation of fogs, which may thus be regarded as suspended dew.

The colour phenomena associated with sunset and sunrise are, as we have seen, considerably influenced by the amount of dust in the air. Mr. Aitkin has said, "When the atmosphere is comparatively free from dust, the colouring is cold, but the lighting is clear and sharp; and, when there is much dust, there is more colour on the mountains and clouds, and in the air itself, and the colouring is warmer and softer."

The amount of haze, too, is directly dependent upon the amount of dust in suspension in the atmosphere. A clearness of the air is usually indicative of a comparative absence of fine particles, whereas haziness is most often the outcome of a large amount of dust.

"Much of the dusty impurity discharged into our atmosphere from artificial sources, by volcanoes, and by the disintegration of meteoric matter, falls to the ground, but much of it is so fine that it will hardly settle. The deposition of vapour on these very small particles seems to be the method adopted by nature for cleansing them away; they become centres of cloud particles, and ultimately fall with the rain."[1]

The absence of ultra-violet waves in direct sunlight, of which mention has already been made, is due in a large measure to atmospheric dust. Mr. S. P. Langley has also shown that the lower layers of the atmosphere often appear to transmit radiations of long wave lengths as readily as higher strata—a result which tends to show that suspended dust exerts little or no influence on the transmitting power of air for these radiations.

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[1] Aitkin, see *note*, p. 80.

Selective Diffusion by the Atmosphere.—It is often said that the atmosphere of the earth is like the glass of a greenhouse, which lets the light rays from the sun pass through it, but prevents the escape of dark rays radiated from the ground. This is true in a general sense; but, though the effects are similar, the causes are different. It has already been pointed out that the air acts upon radiant energy (both light and dark) in two ways, viz., by selective diffusion and selective absorption. The whole of the air, with the myriads of minute particles in it, diffuse or scatter the light passing through it from the sun. Light, as the student has already learned, is produced by waves in the ether; and there is a gamut of colour extending from red, which is due to waves of a certain length, to the blues, which are produced by much smaller waves. Now, in traversing the atmosphere, the sun's rays are diffused by an amount depending upon their wave lengths, rays of small wave length being diffused or scattered to a much greater extent than rays produced by longer waves. The blue colour of the sky is a consequence of this selective action, a greater proportion of blue light being scattered than of red. In the case of the ultra-violet rays, which are of even smaller wave length than blue rays, the diffusion is extraordinarily great; but the action becomes less and less as the wave length increases, until in and below the red the rays are practically unaffected by the scattering influences of the air. Since this is so, it will be evident that the long waves radiated from the earth could pass through the atmosphere into space without undergoing much loss by diffusion or scattering, even though they may be otherwise stopped.

Causes of Sunset Effects.—When the sun is rising or setting, and when it is seen through fog, it no longer appears white, but yellow or red. The reason is that at such times the original rays are robbed of so large a proportion of the short waves (blue light) by scattering in the atmosphere, that what is left is chiefly yellow and red light produced by waves which are not so much affected by atmospheric dust. The red colours of sunset are thus *not* caused to any large extent by the *absorption* of blue rays by the atmosphere, and transmission of red rays in the way that red glass absorbs blue light and transmits the red; they are produced by the *scattering* of blue rays, so that the light which reaches us contains a diminished proportion of blues, and an excess of reds. The action of fine particles in selectively scattering or diffusing light can be strikingly shown by experiment.

EXPT. 16.—Procure a flask of soapy water. Notice that when you look at a light through the liquid, the light is of a yellow or red colour, but when the liquid is looked at sideways with reference to the source of light, it is of a bluish tinge.

EXPT. 17.—Procure a glass trough with flat sides, suitable for placing in front of an optical lantern. Make a solution consisting of one part saturated solution of hyposulphite of soda to thirty parts of water. Also dilute a small amount of hydrochloric acid (one part of acid to eight of water). Fill the trough with the hyposulphite solution and place it in or in front of the lantern, so that a beam of light may pass through it and appear as a round white disc upon a screen. Now add a few drops of the dilute hydrochloric acid to the liquid in the trough. The liquid will in a short time become turbid owing to the precipitation of fine particles of sulphur, and the white disc projected upon the screen will gradually become red, like the sun at sunset.

This experiment exactly imitates the action which makes the sun appear red when seen through fog or an increased thickness of atmosphere. When the hyposulphite solution is clear, the white disc upon the screen may be taken to represent the sun at noon. As the sulphur particles form they scatter a greater proportion of the blue rays of the light of the lantern than of the red; so the disc becomes redder and redder, as does the setting sun, owing to the increase of the thickness of the atmosphere traversed by the rays, and the consequent increased amount of scattering of blue rays by the atmospheric dust. If either side of the trough is observed when the disc appears red, the liquid will be seen to present a pale blue tinge. One is able, in fact, to see the blue light scattered by the sulphur particles, while the red rays pass on unaffected.

The Colour of the Sky.—The general blue colour of the sky is also due to the selective diffusion or scattering of the sun's rays by the innumerable fine particles of impalpable dust which exist in the atmosphere. The rays which enter the atmosphere are of all wave lengths, but we have seen that they are not equally affected by the dust particles. The shorter the light waves, the more are they diffused or scattered by the particles; hence a greater proportion of blue rays (produced by very short waves), are turned aside than red rays (produced by longer waves). Owing to this predominant scattering of the shorter waves of light, the sky assumes a general blue colour. An analogous effect of waves may often be seen at the seaside or on a river. The small waves which strike a boat or log of wood will be seen to be scattered, while the large waves are able to pass on their way.

ELECTRICAL EFFECTS.

The Aurora.—It occasionally happens that a strange luminous appearance, similar in character to the diffused light of the dawn, is seen at night near the north-western horizons of places in the British Isles. This phenomenon is the aurora, and it is produced by electrical discharges in the upper atmosphere. In the northern hemisphere it is called the aurora borealis, and in the southern hemisphere the aurora australis. A general name, which includes both varieties, is the aurora polaris, or polar light.

Characteristics of the Aurora.—The aurora exhibits a great variety of forms, but an examination of all observations of it shows that the different appearances generally belong to one of the following classes[1]:

(1) A horizontal light, like the morning aurora, or break of day. This is the most common form of aurora.

(2) An arch of light, somewhat in the form of a rainbow. This arch sometimes extends completely across the heavens from east to west, and cuts the magnetic meridian almost at right angles. Several parallel arches have been seen at the same time, stretching from the eastern to the western horizon.

(3) Slender, luminous, and frequently tremulous beams or columns, which extend from the horizon for varying distances, and sometimes reach the zenith. Their light is commonly pale yellow, but it is sometimes reddish, and occasionally crimson.

(4) The "corona" of the aurora is a luminous ring, towards

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[1] *The Aurora Borealis, or Polar Light: its Phenomena and Laws.* By Prof. Elias Loomis.

which the bright streamers shooting up from every part of the horizon appear to converge. The direction of the streamers is always parallel to that in which a magnetic dip needle sets itself at the places of observation, and the so-called corona appears in that part of the sky to which the south pole of the dipping needle points, that is, a little south of the true zenith. Since the beams are parallel to each other and to the direction of the dip needle, they do not really converge to the corona around the magnetic zenith, but only appear to do so on account of perspective.

The colour of a faint aurora display is usually white or a pale yellow, but at times a variety of tints are exhibited, the commonest being a rosy colour, or a crimson, which frequently deepens into a blood-red.

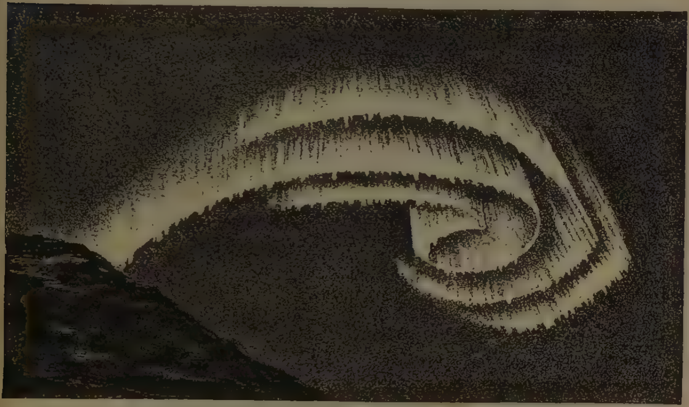

FIG. 31.—Draped Form of Aurora. From Angot's *Aurora Borealis.*

Auroras occur most frequently in the higher latitudes, and are almost unknown within the tropics. From a discussion of all available observations it has been concluded[1] that the aurora seldom, if ever, appears at an elevation above the earth's surface less than about forty-five miles, and that it extends upwards sometimes to an elevation of at least five hundred miles.

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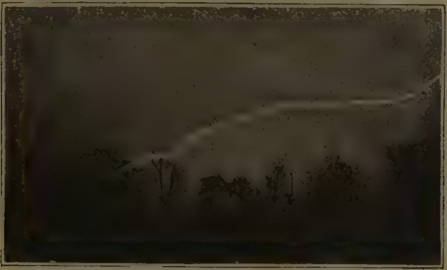
[1] *Aurora Borealis.* Loomis, p. 221

Nature of the Aurora.—The light of the aurora is produced by electric discharges in the upper air, and the different colours are caused by the discharge taking place through air of different tenuities. The colours can be imitated experimentally by passing a discharge, from an electric machine or induction coil, through a tube from which the air can be pumped. When the air in such a tube is of the ordinary density the discharge is nearly white; when some of it has been pumped out, the remainder is rarefied and the discharge through it partakes of a rosy hue; and if the air is further rarefied it assumes a deep rose colour under the action of the electrical discharge. Other evidence that the aurora is an electrical phenomenon is afforded by the fact that during great aurora displays, the telegraph wires are often so much affected, and the needles at the telegraph stations are consequently so greatly disturbed, that it is impossible to read intelligible messages through them.

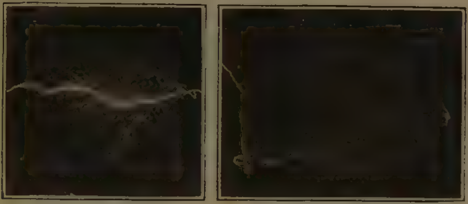
Analysis of the light of auroras has led Sir Norman Lockyer to conclude that it is not entirely due to electrically excited air, but also to the action of the electric discharge upon the meteoritic dust in the upper atmosphere.

Identity of Lightning and Electricity Sparks.—A flash of lightning is an electric spark passing from one electrified cloud to another, or from such a cloud to the earth. The identity of the artificial electric spark with the natural lightning flash was established by Franklin, who showed that thunderclouds are charged with electricity. During a thunderstorm Franklin sent up a kite having an iron point upon it. The string was connected with this point, and to its lower end was attached a key to act as a discharger and a piece of silk ribbon to prevent the discharge from passing through the investigator's body. Franklin found that when there was "thunder in the air," or more correctly, when his kite was in an electrified cloud, he was able to draw from the key electric sparks of precisely the same character as those obtained from an electrical machine in action.

Classification of Lightning Flashes.—Lightning is generally regarded as of three kinds—the ordinary forked lightning, sheet lightning, and ball lightning. Of these only the first need be considered, as sheet lightning is probably not a distinct phenomenon, but the reflection upon the atmosphere of the ordinary discharge taking place below the horizon of the observer; and ball lightning, though certainly a real phenomenon, appears so rarely that practically nothing is known



Stream.



Ramified. *Meandering.*

Sinuous.

FIG. 32.—Photographs of Lightning Flashes. (From the *Quarterly Journal of the Royal Meteorological Society.*)

about it. A large collection of photographs of lightning flashes was made by the Royal Meteorological Society, with the idea of obtaining information as to the forms assumed. Not a single instance of the conventional forked lightning flash depicted by artists appears among the pictures. The great majority bear a close resemblance to the sparks obtainable from electrical machines, and whatever differences occur can easily be explained and even imitated artificially. In addition to the plain stream type of lightning flash, the photographs show what has been termed ramified or branched lightning, beaded lightning, and meandering or knotted lightning Fig. 32. These forms have been described as follows :—

1. Stream lightning, or a plain, broad, rather smooth streak of light.

2. Sinuous lightning—a stream of light which follows a sinuous and wavering course. This is by far the commonest type.

3. Ramified or branched lightning—a form strikingly suggestive of a river in a map. It is not like a simple stream, however, but one into which a number of tributaries flow.

4. In beaded lightning there occur a number of bright spots, giving the flash the appearance of an irregular string of lustrous beads.

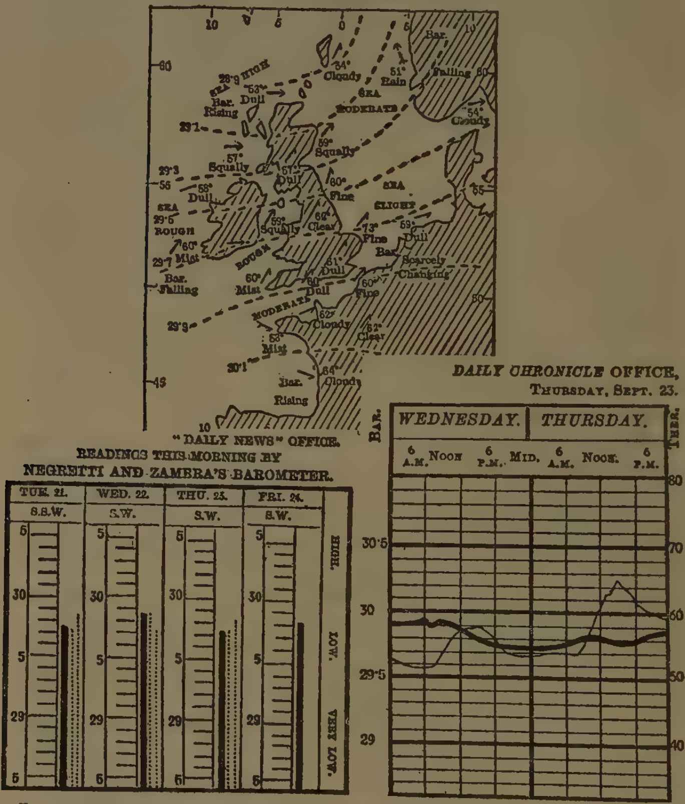
5. The meandering lightning, in which the flash appears to take a very circuitous and roundabout path, perhaps forming a nearly closed loop, or even a complete knot. This remarkable effect is probably the result of an optical illusion ; for though the different parts of a flash may seem to approach or cross one another, their actual distances from the observer may differ considerably.

ATMOSPHERIC MOVEMENTS.

Weather Charts.—With a view to ascertaining the laws which govern the weather conditions, it has become customary to record the atmospheric changes which occur at the different observing stations scattered over the various countries of the civilised world. These observations are recorded in different ways in the form of *weather charts*. Every one is familiar with one or other of these in some leading newspaper. They are of many kinds ; but we will content ourselves with describing the plans adopted by the *Times*, *Daily Chronicle*, and *Daily News* respectively. Though the methods adopted vary in the different cases, yet in them all the data collected are very much the same; and these include such observations as those of the pressure, temperature and hygrometric state of the atmosphere; the rainfall, the amount of bright sunshine, condition of the sky, the direction of the wind, and so on. A system of letters and symbols of fairly general application has grown up, but we will only refer to those which are used in the case of the three examples enumerated, and which are employed in the actual charts we have reproduced.

The "Times" Weather Chart.—The meteorological conditions are recorded in the *Times* upon a sketch map of part of north-west Europe, such as is shown in Fig. 33. The height of the barometer at 8 a.m. and 6 p.m. every day at the observing stations throughout the British Islands and the other countries on the map, is telegraphed to the Meteorological Office in London. These readings are marked upon the map, at the points representing the positions of the stations from which they are received, as is shown in our illustration. Dotted lines are then drawn joining in those places where the pressure is the same; and these lines of equal pressure, called *isobars*, are seen represented in the figure with the reading of the barometer appended to them. In addition to these isobars a reference to the maps shows scattered thermometer readings which represent the shade temperature at the time stated. The direction of the wind at the different stations is given by the arrows, and if the arrow has but one barb it signifies that a light wind only is blowing at the time of observation in the locality represented by the position of the arrow, whereas an ordinary arrow with two barbs signifies a fresh or strong wind. Such words as "Gloomy," "Dull," "Cloudy," "Showery," are a rough indication of the appearance of the weather in the districts represented by their positions.

These isobars are of the greatest value in enabling the meteorologist to study the distribution of atmospheric pressure over large areas. They are filled in for differences of one-tenth of an inch in the barometric reading. If a line be drawn such that it is perpendicular to every isobar through which it passes, it is clear that its slope will represent the rate at which the pressure alters; in those cases where the distance between two


THE TIMES.

WEATHER CHART, THURSDAY, SEPT. 23, 6 P.M.

"DAILY NEWS" OFFICE.

READINGS THIS MORNING BY NEGRETTI AND ZAMBRA'S BAROMETER.

DAILY CHRONICLE OFFICE, THURSDAY, SEPT. 23.

FIG. 33.—Graphic representations of Barometric Height adopted in three London newspapers. Reproduced from the issues of September 24, 1897.

consecutive isobars is great, the steepness of the line will be very little; whereas if the pressure changes at short intervals its slope will be very considerable. Such a line graphically represents the pressure *gradient.* As we shall see more fully later the force of the wind increases with the steepness of the barometric gradient, which we may define as the *difference of pressure for a given unit of distance.*

The "Daily Chronicle" Weather Chart.—The method adopted by this newspaper is different. The chart takes the form shown in Fig. 33, where the thick line shows the variation in the height of the barometer during two days, viz., that of the issue of the paper and the preceding day. The thin line shows the shade temperature for the same interval, and also the maximum and minimum readings for the two days.

The "Daily News" Weather Chart.—The barometric readings are recorded in a different manner by the *Daily News.* Instead of employing the continuous curve of the *Daily Chronicle* or the isobars of the *Times*, the plan shown in the accompanying reproduction from the issue of Sept. 24, 1897, is employed. The black lines show the height of the barometer at 1 o'clock a.m. for three or four consecutive days. The dotted lines indicate the highest and lowest readings observed during each of the days referred to in the chart. The temperatures are recorded in this paper by means of a short paragraph giving the reading in the open air at the same hour as the barometer record refers to.

Movements of the Air in Cyclones and Anticyclones.—As the student has already learnt, a wind always blows from a place where the pressure is high to one where it is lower, and the force of such a wind depends upon the rate of the difference in pressure between the two places, that is to say upon the barometric gradient. Moreover a study of the direction of the wind side by side with the distribution of the isobars reveals the fact that the wind moves along lines which are nearly coincident with the isobars, but which tend to cross from the higher to the lower ones. It soon becomes evident, if the isobars are regularly drawn for consecutive diurnal observations of pressure, that the isobars often take the form of closed curves which include an area of low barometric pressure. Consequently, from what has been just remarked about the direction of the winds compared with the isobaric lines, it follows that the winds are also moving in curves roughly coincident with the lines of equal pressure.

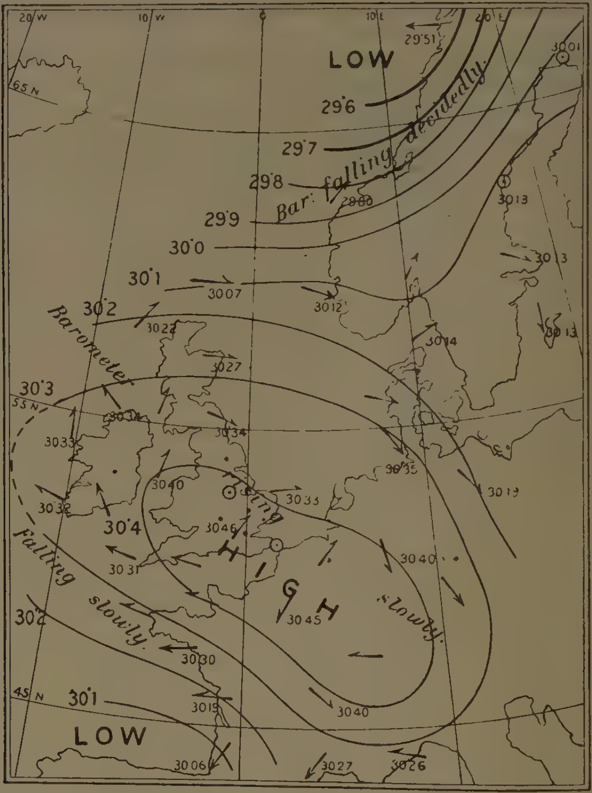


FIG. 34.—Anticyclone of March 20, 1893, with Cyclone conditions in the north part of the Map. (After Harding. Reproduced from the *Report of the Chicago Meteorological Congress.*)

Such a condition of things, where a district of low pressure is surrounded by zones of higher pressure, constitutes what is known as a *cyclone* or *depression;* or in America as a *low.* The curved path which the wind follows in such a cyclone is really a left-handed spiral which results from the rotation of the earth affecting what would otherwise be a simple radial motion of the wind towards the centre of the low-pressure area. As is sometimes said, the motion is opposite to that of the hands of a watch or anti-clockwise. The ultimate result of cyclonic movements, such as we have just described, is the formation of an upward current of air above the central low-pressure area, with the consequent tendency for air to descend from the regions around to take its place. This continued ascent of air must cause an excess of pressure in higher strata, with a diminution of pressure in those places from which air has been drawn to supply the upward current. Whether this explanation is sufficient or not, the form assumed by the isobars at some periods of observation reveal a condition of things exactly opposite to that in a cyclone, viz., a high pressure area surrounded by belts of lower and lower barometric height. Such a phenomenon constitutes an *anti-cyclone.* In anti-cyclones the air movements take the form of right-handed outward moving spirals, or, what is the same thing, the winds move in a clock-wise manner. It has been found too that the winds are generally stronger in cyclones than in anti-cyclones.

The superficial extent of a cyclone is sometimes very great, reaching in some cases a thousand miles across, but there is always a tendency for such extensive cyclones to subdivide into smaller ones. Most often one of the subdivisions is a cyclone of greater intensity than the others, and its intensity generally gradually increases to a maximum, while the others disappear. Another point of interest is that the cyclone is often drawn out, as it were, in one direction, making its form oval, with the longer diameter at least half as great again as the shorter. The rate of advance of a cyclone varies within very wide limits. "Van Bebber gives, as the average of 1,676 cases, a mean velocity of 27 kilometres per hour, the highest average occurring in October (31 km.), the lowest in August (23 km.)."[1]

In middle temperate zones, where the prevalent winds are westerly, the areas of low or high pressure, as the case may be, move from west to east along certain more or less well defined tracks; while in the torrid zone, where, as the student has previously learnt, we have north-east trade winds in the northern, and south-east winds in the southern hemisphere, blowing with great regularity, there are comparatively few cyclonic disturbances.

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[1] Dickson's *Meteorology*, p. 71.

Comparison of Cyclones and Anti-cyclones.[1]

CYCLONES.	ANTI-CYCLONES.
Winds.	
1 Strong in force; at times severe gale, or hurricane.	1 Light in force, often calm.
2 Circulate left-handed round the centre of the system.	2 Circulate right-handed round the centre of the system.
3 Draw in spirally *towards* the centre.	3 Draw out *from* the centre towards the neighbouring cyclones.
Temperature.	
1 Low in summer.	1 High in summer.
2 High in winter.	2 Low in winter.
Weather.	
1 Rough and squally.	1 Quiet and dry.
2 Rain in summer, snow in winter, thunderstorms in both seasons, but especially in summer.	2 Cloudless and bright in summer, with haze at times; foggy or bright in winter.

Formation of Cyclones and Anti-cyclones.—It has been shown[2] that the general circulation of the atmosphere can be explained as the result of convection currents set up by the sun's heat and modified in direction by the earth's rotation. Cyclones may be regarded as stormy interruptions of atmospheric circulation. It is difficult to account satisfactorily for their formation, but the weight of evidence seems to show that they are simply enormous eddies generated in the currents moving polewards at great heights above the earth, the gyrations being communicated through the atmosphere down to the earth's surface. Another theory is that cyclones are independent of the general circulation of the atmosphere, and are convectional whirls set up by local conditions, the turning being a consequence of the earth's rotation. According to this theory, when, on account of greater heat, or a greater amount of aqueous vapour, the atmosphere at any place becomes more rare than the surrounding portion, it ascends, and the surrounding heavier atmosphere flows in to take its place. The air in the ascending current is cooled by expansion as it gets into higher levels, and the vapour in it is condensed. The result of this condensation is the liberation of latent heat, which, by increasing the rarefaction of the air, would tend to make the upward current flow upward still more rapidly than before. It is unnecessary here to discuss the pros and cons of the rival theories; possibly both are true to some extent. Tropical cyclones occur in regions and seasons where high temperatures prevail, and there is no difficulty in thinking that they are really violent convectional whirls set up by local differences of temperature, and supplied with much of their energy from the latent heat of the vapour which is condensed to furnish their heavy rains. Cyclones and anti-cyclones in temperate latitudes cannot, however, be so easily explained, because they are more frequent and more violent in winter than in summer, whereas the reverse would apparently be the case if the convectional theory were true. Another objection to the theory is afforded by observations of the temperature of air at high and low levels during cyclonic and anti-cyclonic conditions. It has been found that during anti-cyclonic conditions the temperature of the air above an altitude of about six thousand feet is from 6° to 10° F. higher than it is during the passage of cyclones, in other words, the law of decrease of temperature with increase of altitude is reversed during anti-cyclonic weather.

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[1] Gaster, *Q. J. Roy. Met. Soc.*, July 1896.

[2] *Physiography for Beginners*, p. 228.

The theory that cyclones are eddies in the atmosphere similar to whirls in a river has a mass of evidence to support it, and is held by most leading meteorologists. According to this view,[1] "the storms of the temperate zone originate not in the convective ascent of warm, damp air, but in great vortical movements of the upper air-currents which commence over the equator as the anti-trades and set continuously towards the poles, being gradually diverted eastwards in consequence of the earth's rotation. Owing to the spherical form of the earth's surface, these currents become irregularly congested as they necessarily converge on reaching higher latitudes, and thus give rise to anticyclones, or tracts of excessive accumulation and pressure, and to cyclonic vortices in the intervals."

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[1] The whole subject is discussed in *Nature*, vol. xliii., pp. 15, 81.

Designation of Atmospheric Movements.—In addition to the great cyclonic and anti-cyclonic movements of the atmosphere, there are several kinds of local disturbance, descriptions of which are given in the book which preceded this.[1] It is worth while to give here, however, if only for the sake of exactness of meteorological nomenclature, a number of definitions issued by the United States Weather Bureau. The definitions are as follows:—

A storm is a disturbance of the ordinary average conditions, and refers to unusual phenomena, and, unless specially qualified, may include any or all meteorological disturbances, such as wind, rain, snow, hail, thunder, etc. This word may be specifically qualified by some peculiarity, that is, sandstorm or duststorm (such as the *simoom*), hot wind (such as the *sirocco*), cold windstorm (such as the *norther*), cold rainstorm and snowstorm (such as the *blizzard*).

A hurricane or *typhoon* is a large stormy area, often several hundred miles in diameter, within which violent winds circulate around a centre. The centre of a hurricane or "typhoon" is a comparatively calm region, where even the clouds break away and the rain ceases; whereas the centre of a thunderstorm is the region of greatest intensity of wind, rain, or lightning.

A tornado is a very much smaller region, usually less than two miles in diameter, within which even more violent winds prevail. In the typical tornado these violent winds circulate about a central axis, rapidly ascending at the same time and forming a funnel-shaped cloud whose base is at the average cloud level; but many destructive winds have been classed as tornadoes which are not circulating about such a funnel-shaped cloud or vertical axis, but which are either blowing straight ahead on the earth's surface, as in the "derecho" or straight line wind, or which have a quasi-rotation around a horizontal axis, as in the blast that accompanies the front of a "norther" or the gust in front of the heavy rain of a thunderstorm. The true tornado is rare, and should be separated from the numerous destructive winds, squalls, and gusts which are usually called tornadoes, hurricanes, cyclones, tourbillons, and other high-sounding names.

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[1] *Physiography for Beginners*, pp. 231-4.

A whirlwind is any revolving mass of air, and includes at one extreme the hurricane, and at the other extreme the dust-whirl of our street corners.

A cyclone is a mass of air circulating around a centre; the lower portion of the air near the earth's surface has a vorticose movement in towards a centre, while the upper layers have a movement out from a centre; the line joining the upper and lower centres is the axis of the cyclone; the direction of rotation is the same in both upper and lower layers; in the northern hemisphere this rotation is said to be in a negative direction, or opposite to the diurnal motion of the sun in azimuth, and opposite to the movement of the hands of a watch lying with its face uppermost.

An anti-cyclone is a mass of air also circulating around a centre, but the lower layer of air has a movement out from a centre, and the direction of rotation is opposite to that of a cyclone, being positive in the northern hemisphere.

The terms "cyclone" and "anti-cyclone" do not describe phenomena that can be observed by one observer or at a single station; they should, therefore, not be used in the description of local phenomena; they represent generalisations based upon the charting and study of winds and clouds observed at many stations, and should only be used when the nature of the rotation of the winds has been clearly demonstrated or can be safely inferred.

The terms "cyclonic winds," "cyclonic system," and "cyclonic rotation," are equivalent to "cyclone." The outer portion of a cyclone generally has feeble winds and fair weather; therefore a hurricane, tornado, or whirlwind is only a small part of a cyclone.

CHIEF POINTS OF CHAPTER V.

It is colder as we ascend in the atmosphere because (*a*) the air does not receive so much heat by contact with the general level of the earth, (*b*) the air is more rarefied, and, consequently, it is not so well able to prevent radiation as the denser air at lower levels.

In consequence of Atmospheric Refraction the sun is seen before it has actually risen and after it has actually set. Absence of atmosphere would mean absence of dawn and twilight. The greater the thickness of atmosphere through which the sun's light has to pass at the time of sunrise or sunset, the longer is the twilight.

The Cause of a Mirage is an increase of density of air from the earth's surface upwards. This inversion of the usual atmospheric density is caused by the land surface getting very hot and heating the air in immediate contact with it, so that the air expands considerably.

The Air acts upon Radiant Energy by (*a*) selective diffusion, (*b*) selective absorption. The former is exerted by the whole mass of the air; the latter chiefly by the water vapour and carbon dioxide in the air.

The Blue Colour of the Sky is a consequence of selective diffusion exerted by the air and the dust particles in it, upon the light from the sun, more blue light being diffused than red.

The Cause of Sunset Effects is the scattering or diffusion of the light of the sun, by the air and the dust particles in it, more blue light being scattered than red. As the sun sinks towards the horizon, it has to shine through a greater thickness of atmosphere, consequently a greater amount of the blues in sunlight are diffused, and an excess of reds reaches the earth.

The Atmospheric Absorption of Radiant Energy is chiefly due to the presence of water vapour and carbon dioxide. The action is small for light coming from the sun, and very great in the case of dark radiations from the earth. The escape of heat rays from the earth is thus prevented.

The Dust and Fine Particles in the Atmosphere cause the condensation of moisture before the air is really saturated with water vapour, increases the radiating power of air (thus increasing the power of cooling), and assists in robbing sunlight of its ultra-violet rays.

The Aurora Polaris is a luminous phenomenon produced by electric discharges in the upper air. The streamers of an aurora lie parallel to the direction of a magnetic dip needle at the place of observation.

Lightning is caused by the discharge of electricity from one thunder cloud to another or to the earth. The chief forms of lightning flashes shown upon photographs are (1) stream lightning, (2) sinuous lightning, (3) meandering lightning, and (4) branched or ramified lightning. Forked lightning is a creation of the artist and does not occur in nature.

Cyclones and Anti-cyclones.—During cyclonic conditions in the British Isles the weather is very unsettled, with gales in winter and thunderstorms and heavy rain in summer. At the centre of a cyclonic system the barometric height is lowest. An anti-cyclone in the British Isles exhibits quiet conditions of wind, barometer and weather, with a low temperature in winter and a high temperature in summer. At the centre of an anti-cyclone the barometer is highest.

The Theories of the Formation of Cyclones are:—(*a*) that cyclones are eddies produced in the upper atmosphere by the currents moving polewards; (*b*) that they are local whirls set up in the atmosphere by local differences of temperature.

QUESTIONS ON CHAPTER V.

(1) What do you learn from the statement that on one day the barometer indicated 29 inches and on another day 28 inches? State what you know of the causes that produce this difference.

(2) If you ascended to the height of $3\frac{1}{2}$ miles in a balloon, carrying a barometer and a thermometer, state—

(*a*) The indication which would be given by the barometer.
(*b*) Your explanation of this.
(*c*) The indication which would be given by the thermometer.
(*d*) Your explanation of this.

(3) Carefully explain what is meant by a "barometric gradient." What is decided by the steepness or otherwise of such gradient?

(4) What do you understand by the terms "anti-cyclone" and "cyclone"? Explain carefully the distribution of barometric pressures in the areas where such phenomena are being manifested.

(5) What is meant by an isobar? Give the general characteristics of a form of weather chart in which isobars bear a prominent part.

(6) Compare and contrast the phenomena associated with cyclones and anti-cyclones.

(7) What are the probable causes which lead up to the development of a cyclonic disturbance?

(8) Why is the sky blue on a fine day? What part is played by dust particles in deciding the shade of blue at any particular time?

(9) Explain the formation of a mirage.

(10) If the earth had no atmosphere, how would the duration of daylight differ from what it is at present?

(11) Explain why we are able to see the sun after it has sunk below the horizon.

(12) Distinguish between the effects of selective diffusion and selective absorption produced by the earth's atmosphere.

(13) Describe the influence of the water vapour and carbon dioxide in the atmosphere upon the transmission of radiations.

(14) How is it that the sun appears to be redder at sunset than it is at noon?

(15) What is an aurora? What is lightning? How do you suppose these phenomena are produced?

(16) What are the theories which have been put forward to explain the formation of cyclones?

(*a*) Describe the cyclonic movements of the atmosphere.
(*b*) Describe the anti-cyclonic movements of the atmosphere.
(*c*) What is the direction of these two kinds of movements in the northern and southern hemispheres respectively?
(*d*) How does the study of these movements enable forecasts of the weather to be made?

(17) What important part does the water vapour and the carbon dioxide, which is always present in the air, play in modifying the temperature of any locality?

(18) Give a short account of Tyndall's work on the absorbing power of aqueous vapour in the atmosphere.

(19) Write an essay on the causes and modifying influences at work in producing the colour effects at sunrise and sunset.

(20) Where are the phenomena collectively known as auroræ best seen? What causes are generally supposed to explain their occurrence?

(21) Specify the various forms into which lightning flashes may be classified.

CHAPTER VI

ATMOSPHERIC PHENOMENA IN RELATION TO CLIMATE

HYGROMETERS

WATER vapour is always present in the atmosphere, but its amount varies from time to time depending upon the temperature of the air and other causes. It often becomes of great importance to determine the amount of the water vapour present at any given time; and as our senses are not trustworthy guides, since the sensation of dryness or otherwise depends rather upon whether the air could absorb more moisture than upon the actual amount of vapour present, it is necessary to have some instrument which will measure the actual quantity of gaseous water in the atmosphere. Such instruments are known as *hygrometers*. It is usual to measure the hygrometric state of the atmosphere at the time of the experiment—that is, to ascertain the ratio between the amount of vapour actually present and the maximum quantity it could take up at the temperature of the experiment. There are many kinds of hygrometers, and we shall proceed to describe a few of them.

Chemical Hygrometer.—This form of instrument measures the actual quantity of vapour present in a given volume of air. It consists simply of a series of U-tubes in which are placed some dehydrating agent, or substance which absorbs water with great avidity. Calcium chloride, strong sulphuric acid, and phosphorous pentoxide are such substances. The tubes and their contents are weighed before and after the experiment, which consists in drawing a known volume of air through these tubes by means of an aspirator. The increase in weight of the tubes measures the amount of the water vapour in the given volume of air.

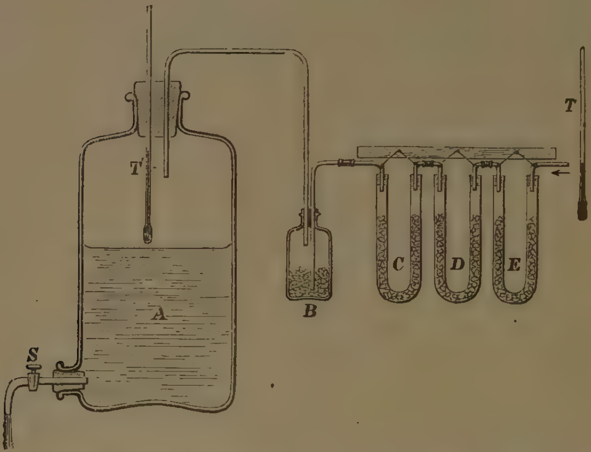

FIG. 35.—A Chemical Hygrometer. *B*, contains strong sulphuric acid; *C*, *D*, *E*, contain calcium chloride; *T*, *T′*, are thermometers; *A*, is an aspirator.

Mason's Hygrometer.—Mason's instrument consists of two precisely similar thermometers, suitably attached to a board, as in Fig. 36. Round the bulb of one of the thermometers is tied a piece of muslin, to which cotton threads are attached, and which hang down into water kept in a glass, which is supported as shown in the figure. The instrument depends for its use upon two facts which have been already brought before the student's attention. The first is that water is only vaporised at the expense of a certain amount of heat; and, secondly, the quantity of water vapour which air can take up at any temperature depends upon the amount already contained by it. Water rises up the cotton threads by the force known as capillary attraction, and consequently keeps the muslin moist. The water on the muslin evaporates, getting the heat necessary for evaporation from the bulb of the thermometer which it surrounds. The thermometer is thereby cooled, and the column of mercury sinks. This continues until the air round the bulb is saturated and evaporation ceases. Thus the wet-bulb thermometer records a lower temperature than the one with a dry bulb. The difference between the readings is greater the drier the air at the commencement of the observation, and we have a means of estimating the amount of water-vapour present by seeing how much more must be added to saturate it.

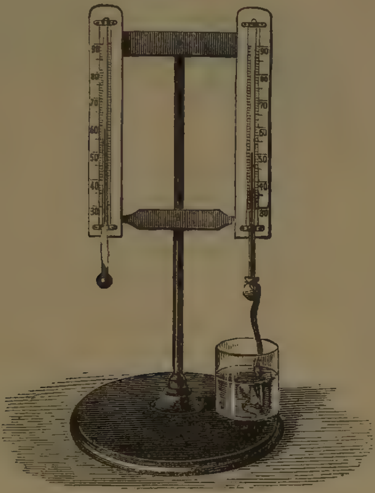

FIG. 36.—Mason's Hygrometer.

Daniell's Hygrometer.—A reference to Figure 37 will show the student that Daniell's hygrometer consists of a tube bent twice at right angles, with a bulb at each end. The bulb A, which is made of black glass, is half full of ether, and there is nothing but ether vapour in the other parts of the tube. A very delicate thermometer is fixed in the longer arm, and its bulb dips into the ether. The bulb B is covered with a piece of muslin which is tied on to the tube. There is a second thermometer attached to the wooden upright which carries the apparatus. The instrument is employed in the following manner. Ether is dropped on to the muslin cover of the bulb B, and, being very volatile, it quickly vaporises, the heat necessary for the volatilisation being extracted from the bulb within the muslin. The cooled bulb causes the ether vapour inside it to condense. But this condensation results in the formation of a further supply of ether vapour from the liquid in the bulb A. The ether in A is vaporised at the expense of the heat of the bulb A, which consequently becomes cooled. This process is continued until the bulb A becomes so cold that the water vapour in the air round it is condensed on the outside of it, and, the glass being black, it at once becomes apparent. At the instant of the first deposition of moisture on the outside of the bulb A, the thermometer inside the bulb is read. The instrument is carefully watched, and as soon as the moisture on the outside of A disappears the inside thermometer is again read. The mean of these two readings is taken as the *dew-point*. The outside thermometer on the upright C gives the temperature of the air.

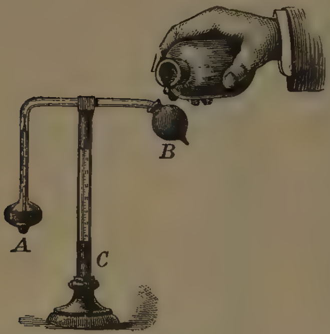

FIG. 37.—Daniell's Hygrometer.

Regnault's Hygrometer.—

EXPT. 18.—Fit up a large test tube in the manner shown in Fig. 38 where *a* is a right-angle glass tube which dips into some ether in the test-tube; *b* is a second glass tube bent at right angles, which just passes through the india-rubber stopper; *c* is a delicate thermometer dipping into the ether; *d* is a piece of india-rubber tubing attached to the tube *a*. A second thermometer is supported in the neighbourhood of the apparatus for recording the temperature of the air. Blow through *d*. This causes the ether to become vaporised, the vapour escaping through *b*. This vaporisation is effected at the expense of the heat in the test-tube, which consequently becomes cooled, and after a time moisture is found to be deposited on the outside of the test-tube. At the instant such deposition occurs read the thermometer *c*; and its reading, in view of the effectual agitation of the ether, is a good measure of the dew-point.

Regnault's hygrometer depends upon the same principle as that exemplified by Experiment 18. The construction of this instrument is shown in Fig. 39. D D are two polished silver thimbles, in which are arranged two test-tubes. The one on the right is half full of ether, and passing down into this ether is a right-angled tube *t* and a delicate thermometer T. There is a side tube in connection with that in the right-hand thimble which puts this test-tube in connection with a hollow tube, U V, which by means of a piece of india-rubber tubing can be placed in connection with the aspirator A. The tube in the left-hand thimble is *not* in connection with U V, the thermometer in it being only used to read the atmospheric temperature. The stopcock shown is turned on, and air is drawn through the ether by means of the aspirator, resulting, as in our experiment, in a deposition of moisture on the outside of the right-hand thimble D. The moment at which this deposition occurs the thermometer T is read and records the dew-point. This reading is a much more accurate determination of the dew-point than either the temperature at the instant of disappearance of the moisture or the mean of such readings.

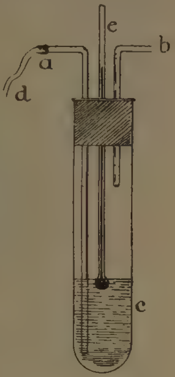

Fig. 38.—Experiment to Illustrate the action of Regnault's Hygrometer.

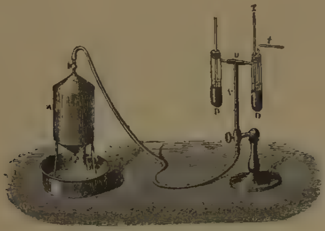

Fig. 39.—Regnault's Hygrometer.

Dines's Dew-point Hygrometer.—A general view and a section of this instrument are shown in Fig. 40. A thin smooth piece of silver, or of black glass, E, rests upon the bulb of a sensitive thermometer lying lengthways in the instrument. Cold water, or a mixture of water and ice is placed in the cup A, and allowed to flow gently through a small tunnel to a small chamber D, where it rises up through a perforated diaphragm to the slab E. The slab is thus cooled and also the thermometer in contact with it. When the cooling has been carried far enough, in other words, when the temperature reaches the dew-point, a film of moisture appears upon the slab, and the temperature at which this happens is shown by the thermometer. The rate of flow of the cold water through the instrument can be regulated by the tap B.

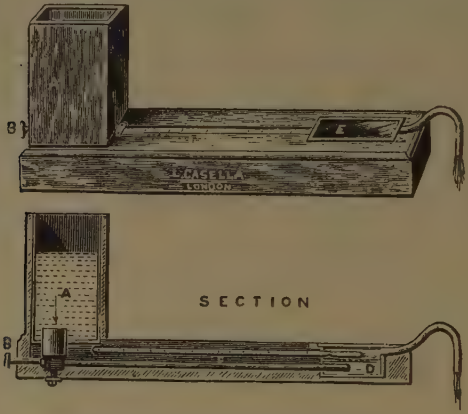

Fig. 40.—Dines's Dew-point Hygrometer.

DEW.

The Condensation of the Water Vapour of the Atmosphere.—Not only is the water vapour of the atmosphere condensed to form rain in the manner which will shortly be described, but under special circumstances of temperature, resulting, it may be, in rapid cooling, or other effects, the condensed moisture may take the form of snow,[1] hail, hoar-frost, or dew. There are several considerations entering into the formation of the last-named which must now be laid before the student, in addition to what he has already learnt on this subject. The essential condition of things resulting in the formation of dew is the more perfect radiation of heat by such substances as green leaves and stones, than by the majority of things. These consequently become cooled, and in their turn lower the temperature of the contiguous stratum of air, thus causing the condensation of its suspended aqueous vapour *upon* these good radiating materials. The temperature at which such precipitation of moisture occurs is known as the *dew-point*, which temperature, as we have seen (p. 104), can be ascertained by one of the many forms of hygrometers. The dew-point is not, of course, constant, but depends upon the relative humidity of the air as well as upon its temperature. Moreover, the deposition of dew is favoured by bright clear evenings, on which occasions radiation may go on quite freely; and by a still atmosphere, so that the cooled layer of air may not be removed before its moisture has been condensed. The actual amount of dew formed upon green leaves is, Mr. Aitkin has shown, considerably augmented by the condensation of the transpired water vapour which issues from the stomata of the leaves.

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[1] The reader should revise Chapter xiv. of *Physiography for Beginners.*

Other Considerations in connection with Formation of Dew.—Colonel W. B. Badgeley has made a considerable number of experiments with a view to determining what part both plants and the earth itself take in the formation of dew, as well as of ascertaining whether the amount due to their agency, if any, varies at different times of the year. He has arrived at the following conclusions[1]:—

1. The earth always exhales water vapour by night and probably a greater quantity by day.

2. The quantity of water vapour given off by the earth is always considerable, and any variation in the quantity is mainly due to the season of the year.

3. The *greater part of the dew comes from the earth vapour.*

4. Plants exhale water vapour and do not exude moisture.

This fourth conclusion is of particular interest, since it indicates that the dew formed on plants does not come out of them in the form of actual droplets, but of vapour which is afterwards condensed into liquid water.

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[1] *Quart. Jour. Roy. Met. Soc.* April 1891.

These observations and experiments were extended by the Hon. Rollo Russell,[1] who experimented with glass tumblers and pans, which he inverted over grass and bare earth and left out during the night. He invariably found that their interiors became covered with a deposit of dew whenever the evenings were clear. With a view to eliminating every objection which could be urged against his conclusions, he inverted similar vessels on earthenware or metal plates placed upon the ground, and under these circumstances dew was never formed on their inside surfaces. There can be little doubt, therefore, that in the first case the dew found covering the interior of the vessels represented the condensed vapour which had been exhaled from the earth or grass.

EXPT. 19.—The reader should repeat Russell's experiments for himself. First, invert a few tumblers, earthenware jars, etc., some on grass and some on soil; also invert similar vessels, side by side with the former, only on metal plates, slates, or tiles. Compare the results in the two cases both on clear nights and cloudy nights.

EXPT. 20.—Choose a clear still evening, and arrange stones, pieces of slate, and sheets of paper on grass, and examine them as soon after sunrise as convenient; notice that the under surface is almost always more bedewed than the upper.

Russell has also shown that the interior of glasses which had been inverted over grassy turf were always more thickly covered with dew than in the case of those which were similarly placed over a turf which had been robbed of its grass. Plates suspended immediately over grass became more bedewed than similar plates suspended over bare earth, results which would have been anticipated from the greater radiating power of grass added to the amount of moisture transpired through its stomata.

It has been established likewise, that the deposition of dew is favoured by a humid atmosphere, especially when it is calm. From what we have seen of the fundamental cause of the formation of dew it is clear that free radiation, which is more likely to obtain in exposed situations, is most effective in the production of dew. Hence most dew is formed on good radiators, and *whatever diminishes the view of the sky diminishes the quantity of dew.*

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[1] *Nature*, vol. xlvii. p. 210, 1892

CLIMATE.

Climate.—The climate of a place is the total effect of all the meteorological conditions which influence it, that is, it is the average of all the kinds of weather which it experiences throughout a year. There are many elements entering into a discussion of the weather of a place at any time. To fully describe it, we must know among other things the maximum, minimum, and average temperature throughout the period under consideration; the amount of the rainfall; the direction and force of the wind; the hygrometric condition of the atmosphere; the amount of bright sunshine. And all these are, as we have seen, subject to a large number of variations. To explain the climate of a place we must, then, be able to account for each of the above elements as it is known in that locality. We have to apply the general knowledge of the atmospheric phenomena gained in our earlier studies of the subject to special cases, and to seek for explanations of the particular modifications which are observed in different districts. The consideration of climate resolves itself into this variety of separate discussions, and we cannot do better than consider some of them separately in more detail. We will begin with rainfall.

1. RAINFALL.

Experiment to represent Formation of Rain.—EXPT. 21.[1]—Procure a cylindrical vase of Bohemian glass of about 20 centimetres in height and 12 in diameter, and fill it half full of strong alcohol—92 per cent.—and cover it with a porcelain saucer (Fig. 41); then warm it over the water bath. It is necessary to warm it up for some time, in order that the liquid and the whole vase and the porcelain cover may attain a high temperature, and be in thermal equilibrium among themselves, but without bringing the alcohol to the boiling point. Remove the whole from the water bath and, being careful not to agitate the liquid, place the vase upon a wooden table and observe it carefully.

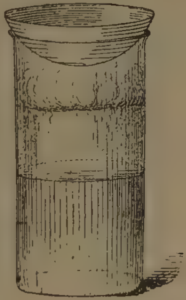

FIG. 41.—Prof. Errera's Experiment to show the Formation of Rain.

The warm liquid continues to send up an abundance of alcoholic vapours. After some minutes the porcelain cover is sufficiently cooled, so that these vapours commence to condense in its immediate neighbourhood. Soon there are thus formed clearly visible clouds, and these in their turn resolve themselves into very fine droplets of rain, which fall steadily, vertically, and in countless numbers into the liquid. The droplets, when measured by means of a horizontal microscope, have an average diameter of from 40 to 50 thousandths of a millimetre; they are sometimes larger, but more frequently smaller. This interesting spectacle may last for half an hour.

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[1] Prof. L. Errera, *Ciel et Terre*, August 1896.

Principal Causes of Rain.—Rain is always caused by the cooling of air containing moisture, but this cooling may be effected in a great variety of different ways. The following are stated by Mr. R. H. Scott[1] to be the principal:—

1. The ascent of a current of damp air into the colder regions of the atmosphere.

2. The contact of warm and damp air with the colder surface of the ground, as in the case of our own west coasts in winter, where the land is colder than the sea surface.

3. The mixture of masses of hot and cold air.

With reference to the first of these causes it must be borne in mind that the ascending air is cooled, not only by its passage into colder regions, but also by the expansion it experiences consequent upon the diminished pressure of these higher strata. That cooling results when such expansion takes place can be shown by a simple experiment.

EXPT. 22.—Compress some air into a metal bottle or cylinder, and allow the vessel to stand for a little while so as to assume the temperature of the room. Afterwards, allow the air to escape, and as it does so let it impinge upon a thermopile or other delicate means of measuring changes of temperature. Notice the cooling of the compressed air when allowed to escape.

When the air is pumped into the pneumatic tyre of a bicycle it is heated, and when it is allowed to escape it is cooled. The experiment just described could, therefore, be performed by allowing the air to escape from a blown-out tyre instead of the bottle or cylinder mentioned.

But in addition to these two causes for the cooling which accompanies the ascent of warm moist air we must add a third, to which we have already (p. 80) called attention, namely, the

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[1] *Elementary Meteorology*, p. 137.

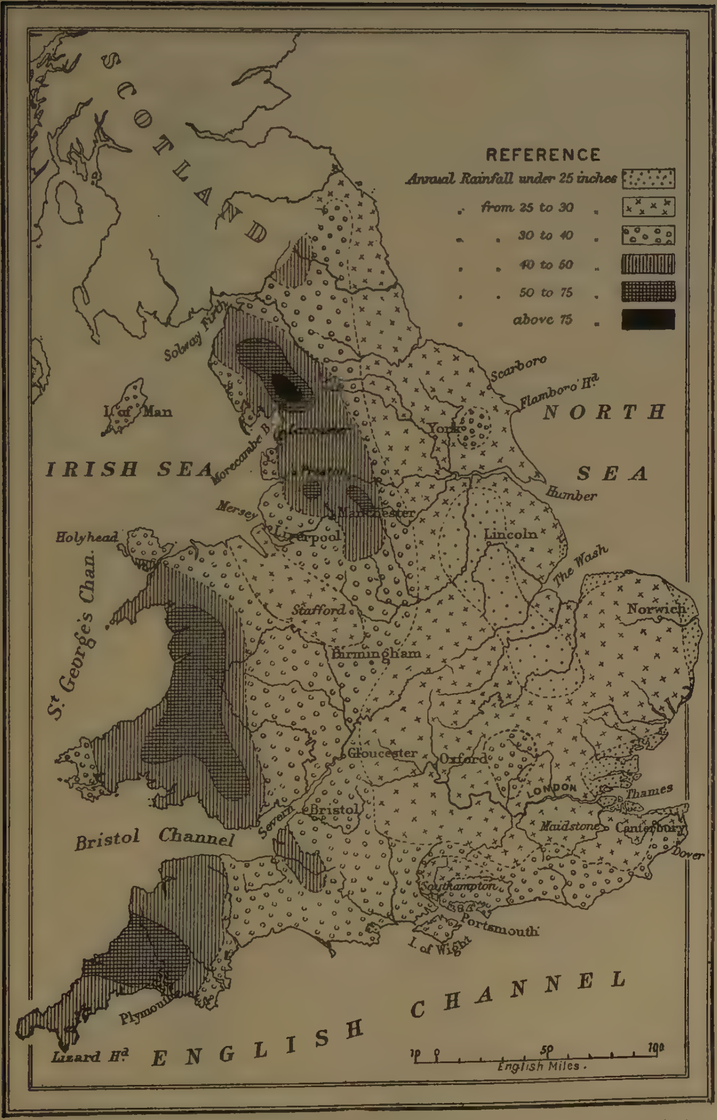

FIG. 42.—Rainfall Map of England and Wales. (Based upon the Map in Huxley's Physiography.)

radiation of heat which takes place from the column of upward moving moist air.

The *amount of rain* which falls in any locality depends partly upon the position of the place upon the earth, and partly upon the character of the neighbouring district.

Rainfall in England.—The distribution of the rainfall in this country (Fig. 42) is at once explained in view of what has been said in the preceding paragraph. Since the mountains of England form three groups arranged down its west coast, viz., those of (1) Westmoreland and Cumberland; (2) Wales; (3) Cornwall and Devon; and since in addition to this the prevailing winds blow from the south-west, the rainfall in these districts will be much higher than elsewhere. The annual rainfall in parts of Cumberland is above 75 inches, while at one place, Seathwaite, it reaches 137 inches, which is the greatest recorded annual rainfall in Europe. In the second of the groups of mountains mentioned, the greatest rainfall occurs in the neighbourhood of Blaenau Festiniog, where the annual rainfall reaches upwards of 75 inches. This amount is also recorded in the third mountainous district, in the locality of Dartmoor. Throughout the Lake country the rainfall is over 50 inches in the year, and the same is true of all the mountainous parts of Wales and the higher portions of Devon and Cornwall. If we draw a line from the middle of the Cheviot Hills almost due north and south to Birmingham, and another from this place to Liverpool, we shall have included an area in the north-west where the rainfall varies between 30 and 40 inches per year. The same numbers apply to that part of the southern counties south of the Downs, and to the parts of Gloucestershire round the Cotteswold Hills. The central parts of England as far east as Oxford possess a rainfall of from 25 to 30 inches, while that of the eastern counties as far west as this university town is below 25 inches in the year.

Where Rainfall is Abundant, and Why.—The mean annual rainfall at different places in the world is shown diagrammatically in Fig. 43. The general conditions favourable and unfavourable to an abundant rainfall were determined by the late Prof. Loomis from an examination of records made in all parts of the world; and the following examples are from an elaborate memoir[1] in which these rainfall observations are brought together and discussed.

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[1] *Contributions to Meteorology.* New Haven, 1889.

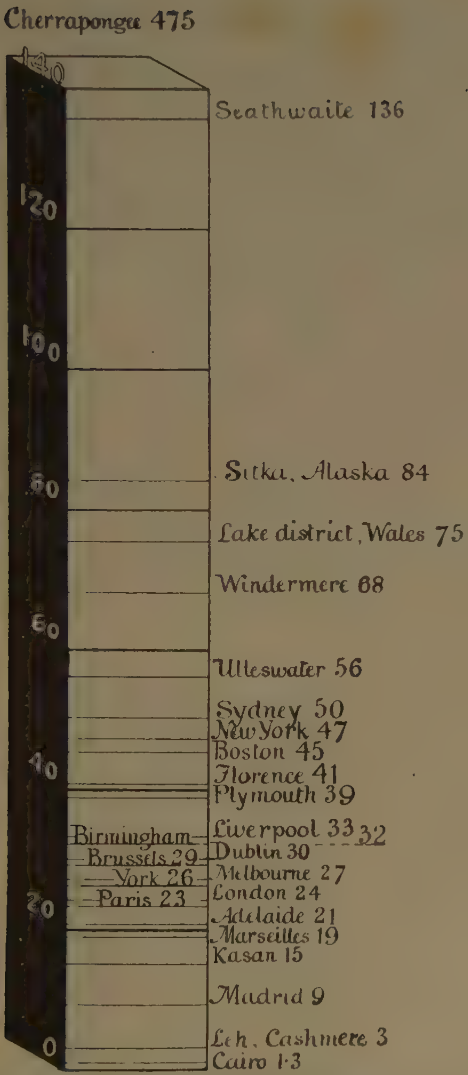

FIG. 43.—Graphic Representation of the Mean Annual Rainfall at Different Places. The figures signify inches of rain.

In the Torrid Zone.—There is, a little north of the equator, a belt, several degrees in breadth, known as the *belt of calms*, within which rain falls almost daily, whereas for a distance of a few degrees on each side of this zone rain seldom occurs. This remarkable persistence of rainy days is produced, as we have already pointed out, by the co-operation of three causes, viz., the cooling which results, consequent upon its passage into higher regions, to the upward moving column of air produced by the collision of the two sets of trade winds in this area; secondly, by the cooling resulting from expansion as it rises; and thirdly by the lowering of temperature which ensues from the radiation of its heat by the aqueous vapour. The belt of calms is thus converted into a belt of rain, which from its position is called the *equatorial rain-belt.*

On Mountains.—On a mountain of moderate elevation the rainfall is usually greater than it is at the level of the sea; and at a certain height the rainfall is from two to three times as great as it is near the base of the mountain. Thus, on the Puy de Dome, France, at an altitude of 4,800 feet, the mean annual rainfall is sixty-one inches, whereas at the base of the mountain, which is only 1,270 feet above sea level, the rainfall is only twenty-five inches. The reason of this is that when a strong wind strikes against any such elevated land, whether in the form of an isolated mountain or as a range of mountains, the moving air is forced up the side into higher atmospheric regions, where it is subjected to the causes we have enumerated in the preceding paragraph, with the result that its vapour is condensed and falls as rain.

Near Oceans.—Nearness to the oceans is of itself conducive to an abundant rainfall. Even where there is no elevated land of any importance to assist in the precipitation of the aqueous vapour, those places which are situated near to the large expanses of water are often found to have a great rainfall. Thus, from the North Sea to the Ural Mountains is a belt of land 2,000 miles long and 400 miles wide, where the changes of level are so gradual that they exert no appreciable influence upon the rainfall. But although near the North Sea, for instance at Norderney in Germany, the rainfall is thirty-six inches, it gradually diminishes on going eastward, and in the eastern part of Russia it is less than half that amount. The prevalent winds in this district blow from the oceans, and what would have been expected happens, the places which the wind first meets rob it of the largest proportion of its moisture.

It is partly on this account, though chiefly because the western coast of Great Britain is more elevated than the eastern, that the rainfall is greater on the west coast than in the eastern counties.

Districts with Excessive Rainfall.—Seven of the most remarkable mean annual rainfalls in the world are shown below:—

Place	Altitude	Mean Annual Rainfall
Cherraponjee, India . . .	4,455 feet	475 inches
Mahableshwar „	4,540 „	260 „
Uttray Mullay „	4,500 „	267 „
Seathwaite, England . . .	422 „	136 „
Sitka, North-West America	20 „	84 „
Valdivia, South America .	42 „	115 „
Hokitika, New Zealand .	12 „	113 „

As an example of the application of the general principles we have found governing an abundant rainfall, it will be interesting to try and account for some of the abnormal observations given in the table above.

Cherraponjee, India.—Cherraponjee is situated at an elevation of 4,455 feet on the Khasia Hills, 200 miles north of the Bay of Bengal. Observations show that nearly all the rain there falls during six months of the year, viz., from April to September. During these months the prevalent wind in the Bay of Bengal blows from the south. When the wind changes to west or north-west, as it does for the most part in the other months of the year, the rain almost entirely ceases. As Prof. Loomis pointed out, these facts indicate that the rainfall on the Khasia Hills is due, therefore, to an upward deflection of the winds as they encounter the range of mountains ; and its extraordinary amount is caused by the unusual combination of the high temperature of the air, with its great humidity, brought about by its journey over the Indian Ocean, and the proximity of the mountains themselves to the ocean, together with, finally, the abruptness with which the range of hills towers up from the sea. The ascent from Sylhet to Cherraponjee, a distance of less than thirty miles, being more than 4,000 feet.

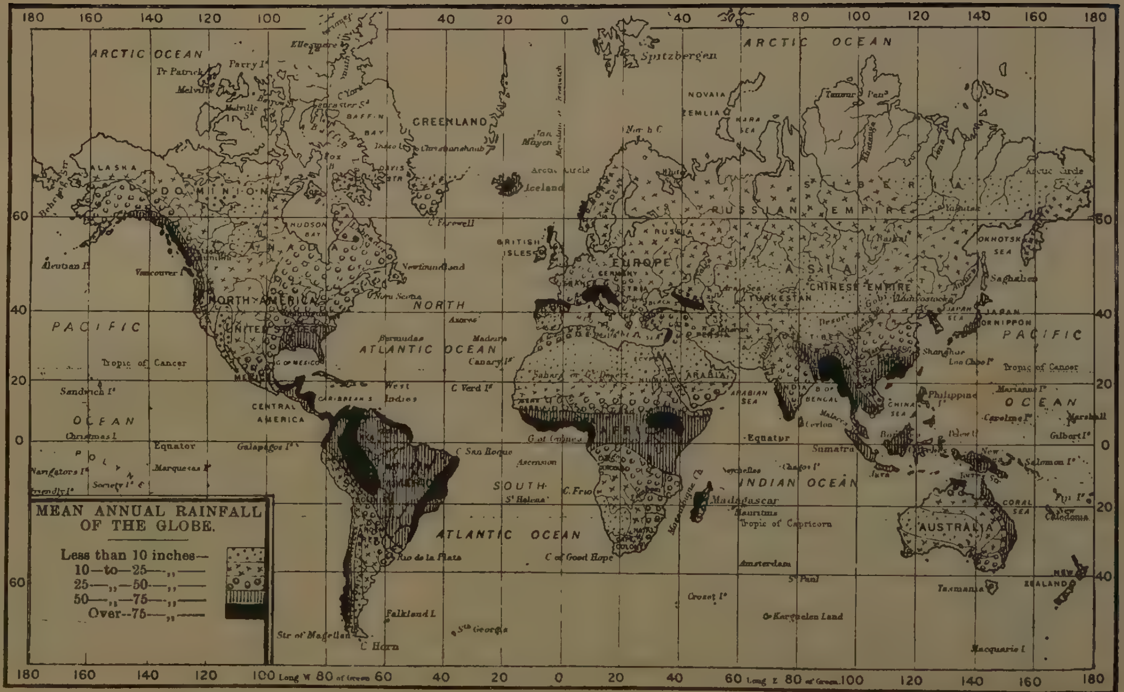

FIG. 44.—Mean Annual Rainfall for the different Countries of the Globe. (After Loomis.)

Mahableshwar and Uttray Mullay.—Both these places are located near the Malabar coast on the west of Hindustan, at practically the same height above the sea level as Cherraponjee in the north-east of the same country. They are near the summit of an incline which extends down to the coast, and there is nothing between them and the sea to obstruct the south-west winds which blow from the Indian Ocean during the summer monsoon. The conditions are, therefore, very similar to those in the case of Cherraponjee, and the rainfall is also very great.

Seathwaite, Cumberland.—This place has the greatest recorded mean annual rainfall of any station in Europe, and its excessive wetness seems to be due to the neighbouring mountains, Skiddaw and Helvellyn, which are very favourably situated for a complete condensation of the moisture of the wet westerly winds.

Sitka, Valdivia, Hokitika.—Sitka, an island situated at the south-west corner of Alaska ; Valdivia, on the coast of southern Chili ; Hokitika, on the west coast of South Island, New Zealand ; all owe their excessive rainfall to their proximity to the ocean, and to the fact of their being the first places to come into contact with the moisture-laden winds blowing from the ocean.

Where Rainfall is Small, and Why.—Again adopting the classification of the late Prof. Loomis, we give the following conditions as unfavourable to a good supply of rain :—

Situation in the Trade-Wind Areas.—Rain is almost unknown over those parts of the Atlantic Ocean where the trade winds blow. But though this is true in mid-ocean, where the uniformity in direction of these winds is never broken, yet over continents, subjected as they are to many disturbing influences, this principle of fresh, uniform winds being unfavourable to rainfall is not so distinctly seen.

On the Leeward Side of Mountain Ranges.—Since the windward side of mountain chains are characterised by their abundant rainfall it follows naturally that the wind, already robbed of its moisture, passing down the leeward side, cannot bring further rain with it, there being no water vapour borne along in its train which can be condensed. This principle is strikingly exemplified in South America. The trade winds, after passing nearly across the continent, encounter the Andes, by which they are forced upward to a great height, and so lose nearly all of their vapour; and when the air descends on the western side it is extremely dry, so that along the Pacific coast there is a narrow belt which is almost rainless. Where a place is so situated that it is surrounded with mountains on all sides or nearly so, the diminution of rainfall due to this cause is still more decided. Salamanca in Spain, with an annual rainfall of ten inches, affords an illustration of this. On the north it is protected by the Cantabrian Chain, on the east by the Castilian Mountains, and on the south and south-east by the Sierra de Guadarrama and its Portugese continuation.

At Great Elevations.—Although a range of mountains 5,000 or 6,000 feet is uniformly marked by a great excess of rainfall, if the mountains rise sufficiently high there is a decrease of rainfall near the summit of the range. Elevated plateaus are also characterised by the dryness of the air and the smallness of the rainfall.

Rainless Districts.—There is probably no part of the earth where rain never falls, but in some districts the mean annual amount of rainfall is very small. We shall call attention to a few examples only of such dry regions, and briefly explain the chief causes of their aridity.

The Sahara.—That part of Africa which lies to the north of the parallel of latitude, 17°N., is well-nigh rainless. The northerly winds which prevail in these regions, both in summer and winter, blow from a cooler into a warmer region, and have, therefore, since their capacity for holding moisture is continually on the increase, the character of dry winds, and on this account the belt of country takes the character of a desert.

Arabian Desert.—The conditions in the Desert of Arabia are very much the same as those of the Sahara. The prevailing winds throughout the year are from the north, and consequently, as they blow from cooler into warmer regions, are dry winds. The result is that the part of Arabia north of the twentieth parallel of latitude is of the nature of a desert.

Tibet.—The mean annual rainfall over the whole of the elevated plateau of Tibet is small, and this is partly owing to the great elevation of the table-land and partly to its position on the leeward side of the Himalaya Mountains. Leh, for instance, situated on this plateau somewhat to the north of Kashmir, has a mean annual fall of only three inches.

The Desert of Gobi.—This desert, sometimes called Shamo, at others the Great Steppe, owes its pronounced aridity to a combination of three causes. It is cut off from the influence of the Pacific Ocean by the Khinghan Mountains, which shut out moisture that would otherwise reach it. The prevailing winds arrive after having already traversed a desert region, and finally the elevation of the district is upwards of 4,000 feet above the sea level.

The Salt Lake Basin.—The great Salt Lake region of Utah and Nevada has a mean annual rainfall of only seventeen inches, a fact which is almost entirely due to the cutting off of the prevailing south-west winds by the Sierra Nevada and the Rocky Mountains. Probably the elevation of the region, which averages about 5,000 feet, also contributes to the dryness of the atmosphere and the smallness of the rainfall.

Interior of Australia.—During the colder months of the year the winds of this district have a general tendency outwards from the interior of the continent, and this is manifestly a condition unfavourable to rainfall. In the summer months the prevalent winds tend inwards towards this central area, which is at this season extremely hot, and the winds in consequence, passing from a colder to a hotter district, are dry, since they become more and more able to take up moisture. It is thus seen that the conditions in Central Australia are very like those in the Sahara during the hottest months there, and that they are also unfavourable to rainfall is seen from the fact that the mean annual amount is less than ten inches.

2. RANGE OF TEMPERATURE.

Range of Temperature.—The amount by which the temperature of a place varies throughout the year is a very important factor in determining climate. If two isothermal maps showing the mean temperatures of the world in January and July are examined, a number of places will be found having the same difference between their winter and summer temperatures. Lines drawn through these places on another map will be lines of equal annual range of temperature. A map of this kind, drawn by Mr. J. L. S. Connolly, is shown in Fig. 45. An examination of the chart reveals the following facts:—

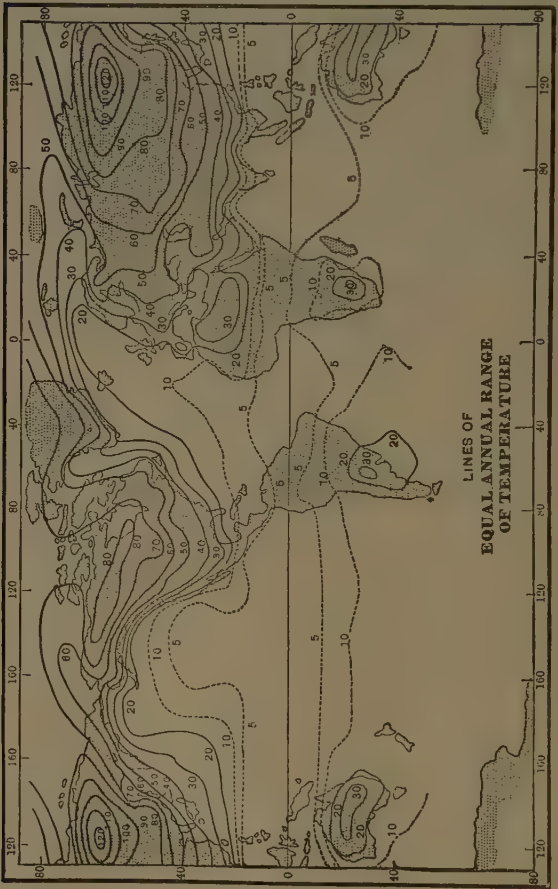

FIG. 45.—Map Showing the Places where the Difference between the Mean Temperatures in January and July, is the same. The degrees are expressed on the Fahrenheit Scale. (From the *American Meteorological Journal.*)

The Torrid Zone is on the whole a region of moderate annual range of temperature, while the North Temperate Zone has extreme variations as compared with the South Temperate Zone, and the Northern Hemisphere has on the whole greater ranges than the Southern. The reason for this is that water areas vary little in temperature during the year, while land areas change their temperatures much more readily. The effect of great land areas in producing large ranges of temperature is well shown on Mr. Connolly's chart. In Northern Asia there is a range of 120°; in northern North America, 80°; in Northern Africa, Australia, South Africa, and southern South America, 30°. It will be noticed that the areas are all far from the equator, and the regions of greatest range are in the Northern Hemisphere.

3. LATITUDE.

Relation between Climate and Latitude.—We have seen that the mean temperature of a place, together with the range of temperature to which it is subject, are potent factors in determining its climate, and we have shown[1] that on the oceans there is a fairly uniform diminution of temperature as we pass from low to high latitudes. This regular variation of temperature with latitude over the oceans is a natural consequence of the obliquity of the earth's axis acting in concord with the thermal properties of water, viz., its high specific heat and bad conducting power. The rays of the sun fall upon the surface in polar regions at a much greater angle than in tropical districts, and at intermediate angles for latitudes between these limits, and as a consequence there is a greater and greater absorption of heat by the atmosphere as the latitude approaches the pole. This explains the difference in the amount of heat received in places at differing distances from the equator. The remarkable constancy in the temperature of the ocean at any particular latitude, which we have remarked in our study of Fig. 45, results from the large amount of heat necessary to warm the water in the first instance, and the slowness with which it parts with this heat after it has once been warmed. Its bad conductivity prevents the heat passing downwards into the mass of the oceanic waters.

But this direct relation between latitude and the mean annual temperature is by no means so simple when we come to consider places situated on the great land masses. The materials building up the solid parts of the earth's crust are possessed of differing specific heats, as well as differing absorptive and conducting powers, all of which constants influence the mean temperature. The consequence is, that the local circumstances vary between wide limits; and since the climate is the resultant of these, as far as they influence the meteorological conditions, we have places of the same latitude with widely divergent ranges of temperatures. Verkhoyansk in Siberia and the Lofoten Islands are both situated in the same latitude; but while the annual range in the former place is only 23°F., in the latter it is as much as 116°F. Nearly as pronounced a difference as this is seen by comparing Bergen in Norway with Yakutsk in Siberia, which differ in position as regards their latitude by only two degrees; yet Bergen has an annual range of but 22°F. as compared with one of 111°F. at the Siberian station. Evidently there are other causes besides latitude determining the climate of a place, and some of these we have already considered.

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[1] *Physiography for Beginners*, p. 213.

4. ELEVATION.

Elevation and Climate.—Incidentally it has been pointed out already how the altitude of a place influences some of the circumstances which help to determine its climate. The temperature diminishes with the height above the sea level, though not regularly. There is a marked, yet not a regular, decrease of about 1°F. for every 300 feet of ascent during the day up to 2,000 feet, and a smaller and similarly variable diminution during the night.

In the same way with rainfall, as we have seen, there is up to moderate elevations a steady increase in the mean annual rainfall, whereas at great elevations the rainfall is very small, and the reason of this has been explained (p. 118).

In hot countries like India it is a matter of common knowledge that climate is modified by height above the sea level. In that country it is customary for Europeans to retire to places in the Himalayas during the hot seasons, because of the more bearable conditions which are experienced there.

It is also interesting to note that the same gradations in the character of the vegetation which are remarked in travelling from the equator to the poles are also observed in ascending a high mountain in the tropics. At the base a profusion of tropical plants abounds, while at the snow-capped summit the only vegetation to be discovered are specimens of an Arctic flora such as are found within the polar regions, while the intermediate journey is through a region which can be divided into zones of vegetation precisely similar to those characterising middle latitudes.

5. PROXIMITY OR OTHERWISE TO THE OCEAN.

Insular and Continental Climates.—The high specific heat of water which, as has been stated, causes a parallelism between the isothermals and the parallels of latitude over oceanic areas, is also instrumental in bringing about a marked uniformity in the climates of islands. Surrounded as they are by water, it is found that they experience a small annual range of temperature only, which in the case of some islands in the tropics amounts to no more than a few degrees—four or five, a fact which gives rise to the expression *oceanic* climate. Though the uniformity in the case of larger islands in temperate zones is not so pronounced, it is still very considerable compared with the decided disparity between the extreme winter and summer temperatures of places far removed from the seaboard of the nearest ocean. Places of this character, like Great Britain or Tasmania, are said to enjoy an *insular* climate, while inland stations like Moscow, experience what is called a *continental* climate. These climate divergences are thus all of them the result of the differences in the thermal properties of land and water surfaces.

6. PREVAILING WINDS.

Climate in relation to Prevailing Winds.—Enough has already been said, under headings previously treated of, upon this subject. The immediate effect of the prevailing winds upon the hygrometric state of the atmosphere, and the amount of rainfall, has been discussed under the question of rainfall. The range of temperature is also influenced by the prevailing winds. For instance, the winds which blow for the greater part of the year in the Sahara, coming from the higher latitudes of Europe, are felt as cold, dry winds, and do much toward lowering the temperature of this district. Or taking the case of our own islands, the west and south-westerly winds, arriving after a journey over the Atlantic Ocean, where they have become saturated with moisture and warmed by the Gulf Stream, are very powerful agents in causing a mild climate on the west coast of this country; whereas, the easterly and north-easterly winds coming from the continent of Europe are colder and drier, and bring about the harsher and more bracing conditions of the eastern counties.

MINOR FACTORS OF CLIMATE.

Other Influences upon Climate.—It has now been abundantly insisted upon that the fundamental factor deciding the climate of a place is the amount of heat which it receives, and that differences in this total are instrumental in bringing about the various effects which have been categorically detailed. This important element in the production of climate is further influenced by such causes as *the slope of a country* towards the sea; should the inclination be in the direction of the mid-day sun the amount of warming experienced will be greater than in those cases where the slope is towards the rising or setting sun.

The influence of oceanic currents is also often instrumental in producing variations of climate. The winter climate of countries on the west of Europe is ameliorated by the warming effect of the Gulf Stream; while cold currents, like the Labrador current, result in a contrary effect in the climate of those countries it influences. The eastern side of the northern parts of the North American continent are cooled by this stream of water from the Arctic Ocean.

Cultivation results oftentimes in profound climatic modifications. The clearing of forest land, which up to a certain point is productive of an increase of temperature and a beneficial diminution of the moisture, may, if carried too far, cause a permanent decrease in the mean annual rainfall, and seriously diminish the productiveness of a country. The extensive draining of a marshy district has been, in several instances, known to result in an increase of its mean annual temperature. It is alleged, for instance, that one of the results of the drainage which has been effected in Great Britain during the past century has caused an increase of one or two degrees in its mean annual temperature.

Climate of the British Isles.—The Meteorological Office recently published an interesting summary of observations of barometric height, temperature, rainfall, and bright sunshine, made during the past quarter of a century at a large number of stations, situated in different parts of the British Islands. The following are a few of the facts brought out by the comparison of results :—

The average readings of the barometer are much lower over the northern portion of the kingdom than in the south during all the winter months, and this explains the great predominance of westerly and south-westerly winds which blow over us from the Atlantic. In the summer the barometer readings are much more uniform over the whole country, and the winds are, consequently, of less strength and more variable in direction. The lowest mean temperature occurs nearly always in January over the whole country, and it ranges from 37°F. in Scotland and the English Midlands to 45°F. at Scilly, and 44°F. at Valentia. The highest mean temperature occurs in July and August, these two months being about equally warm in all parts of the country. The mean at the Scotch stations is 56°F., in Ireland 59°F., and in England 61°F. London and Jersey enjoy the highest summer mean temperature, the average being 63°F. The values of absolute minimum temperature show that in December, January, and February, the temperature occasionally falls below 10°F. in different parts of the kingdom ; but readings below zero are extremely uncommon. Frost may occur in any part of the country in April, and it sometimes occurs in May, except at the extreme western stations. Frost occurs in many parts of Great Britain in September, and is of frequent occurrence in October and November, readings falling below 20°F. in the latter month. As to rainfall, after Seathwaite and its neighbourhood, the heaviest rainfall occurs at Glencarron, where the total fall for the year is 86 in., and at Fort William where it is 77 in. One of the lowest annual rainfalls is 23·3 in. at Cambridge. In London, the total for the year is 24·8 in. The driest part of the year is March in the Eastern and Midland districts of England, April generally in Scotland, Ireland, and the West of England ;

while in the South-west of England it is as late as May. The heaviest rainfall in England is mostly in October; but in Scotland and Ireland it is far more irregular, occurring sometimes in winter and sometimes in summer.

CHIEF POINTS OF CHAPTER VI.

The Climate of a Region is its condition as regards air, temperature, rainfall, winds, sunshine, &c.

Conditions Favourable to Rainfall are:—(*a*) An ascending current of air; (*b*) a mountain or a range of mountains nearly at right angles to the direction of the prevalent wind; (*c*) proximity to the ocean, especially when the prevalent wind comes from the ocean; (*d*) capes and headlands projecting considerably into the ocean; (*e*) great and non-periodic depressions of the barometer.

Conditions Unfavourable to Rainfall are:—(*a*) Fresh winds blowing in a nearly uniform direction throughout the year; (*b*) a position on the leeward side of a range of mountains running in a direction nearly at right angles to that of the prevalent wind; (*c*) a position on an elevated plateau or near the summit of a high mountain peak; (*d*) remoteness from the ocean, measured in the direction from which the prevalent wind proceeds; (*e*) high atmospheric pressure; (*f*) high latitude; (*g*) a position out of the tracks of barometric depression.

Among the Causes regulating Climate are:—(*a*) Latitude; (*b*) elevation above sea level; (*c*) position with reference to the ocean; (*d*) direction of ocean currents and winds; (*e*) slope of land, cultivation of land, and proximity to lakes or to mountains.

Hygrometers are instruments for measuring the amount of water vapour in the air, or for determining the hygrometric state of the air.

The Hygrometric State of the air is the ratio between the amount of water vapour actually present in the air to the maximum quantity it could take up.

Chemical Hygrometers consist of a succession of U-tubes filled with some dehydrating agent such as calcium chloride, or pumice stone soaked in sulphuric acid. The increase in weight of the series of tubes after a known quantity of air has been passed through them represents the absolute amount of water vapour in this quantity of air.

Wet and Dry Bulb Hygrometer.—The temperature of the air is indicated by a thermometer, and the cold produced by evaporation of water vapour is indicated by another thermometer, the bulb of which is surrounded with wet muslin.

Dew-Point Hygrometers.—The essential parts of a dew-point hygrometer are:—(*a*) A glass or polished silver surface upon which moisture condensed from the air can be easily seen; (*b*) a thermometer to show the temperature at which condensation takes place; (*c*) a thermometer to show the temperature of the air at the time of observation.

In *Daniell's hygrometer*, ether, in which a thermometer dips, is made to evaporate; the evaporation produces cold; and eventually a film of moisture appears on the outside of the bulb containing the ether. The temperature at which this occurs, in other words, the *dew-point*, is then shown by the thermometer.

In *Regnault's hygrometer*, ether, or another volatile liquid, is contained in a glass tube, closed at the bottom by a very thin silver thimble. The ether is made to evaporate by a current of air drawn through it, and a thermometer dipping into it shows the temperature when sufficient cold has been produced to cause the deposition of moisture upon the silver.

In *Dines's hygrometer*, a thin smooth piece of silver, or of black glass, rests upon the bulb of a sensitive thermometer. A current of cold water is made to flow under the glass or silver, and the reading of the thermometer when moisture appears on the upper face of the glass or silver is the dew-point.

QUESTIONS ON CHAPTER VI.

(1) State what is meant by the "dew-point," and describe a dew-point hygrometer. How are observations made with this instrument, and what deductions can be drawn from the results of such observations?

(2) How would you proceed to fit up a chemical hygrometer, and when you have made one what could you measure with it?

(3) Describe an experiment to show the principle of Regnault's hygrometer.

(4) Explain the conditions which give rise to—
  (*a*) Abundant rainfall.
  (*b*) Great drought.
And give examples of districts characterised by—
  (*c*) Excessive rainfall.
  (*d*) Absence of rain.

(5) What is meant by the "dew-point"? Explain the construction and mode of use of the dew-point hygrometer.

(6) What are the chief peculiarities in the climate of the British Isles, and to what causes are these peculiarities to be ascribed?

(7) Describe the differences in the climate of the east coast of Labrador and the west coast of Ireland, and state the chief causes to which these differences are due.

(8) Give an example (and in each case describe briefly the causes to which the peculiar climatal features are due) of:—
  (*a*) A district in which the rainfall is abnormally high.
  (*b*) A district with no rainfall.
  (*c*) A district in which the mean annual temperature is much higher than that of other places in the same latitude.
  (*d*) A district in which the mean annual temperature is far below that of places in corresponding latitudes.

(9) What facts have to be determined before the climate of a place can be known?

(10) Describe the general characteristics of he climate of England.

(11) Compare the east and west coasts of England as regards rainfall, and state the reasons for any differences you describe.

(12) Describe some districts in the British Isles, (*a*) where the rainfall is small, (*b*) where the rainfall is large. Explain the causes of the differences.

(13) Name those places where the mean annual rainfall is large, and those where it is small. Explain briefly the influences which determine the rainfall of the places you mention.

(14) What are the chief influences which regulate the climate of a place?

(15) Explain what is meant by mean annual range of temperature, and mention a region where the range is small, and one where it is large.

CHAPTER VII

SEAS AND LAKES

OCEANIC DEPTHS AND DEPOSITS

Modes of Determining Depths of the Sea.—To find the depth of water in any place where it does not exceed about 1,000 fathoms, all that it is necessary to do is to attach to the end of a line an ordinary *deep-sea lead*, which is a prismatic leaden block, about 2 feet in length, and about 100 lbs. in weight, narrowing a little towards the upper end, where a stout iron ring is attached. Before "heaving the lead," it is armed with a thick coating of tallow at its lower extremity, which is hollowed out slightly for the purpose. The line is allowed to run out until the bottom is felt, and the length of it which has been paid out is measured by means of differently coloured strips of bunting tied on to the line at intervals of every 50, 100, and 1,000 fathoms. When the lead reaches the bottom, a sample of the material forming the sea floor sticks to the tallow, and affords evidence of the fact of the bottom really having been touched. The approximate depths of the ocean, determined by soundings of this character, are shown in Fig. 46.

For Greater Depths.—The simple plan described is not suitable for depths of much more than 1,000 fathoms, for the following reasons[1] :—

1. The weight is not sufficient to carry the line rapidly and vertically to the bottom.

2 When a heavier weight is used, an ordinary sounding line is

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[1] See *Depths of the Sea.* Sir C. Wyville Thomson, p. 207.

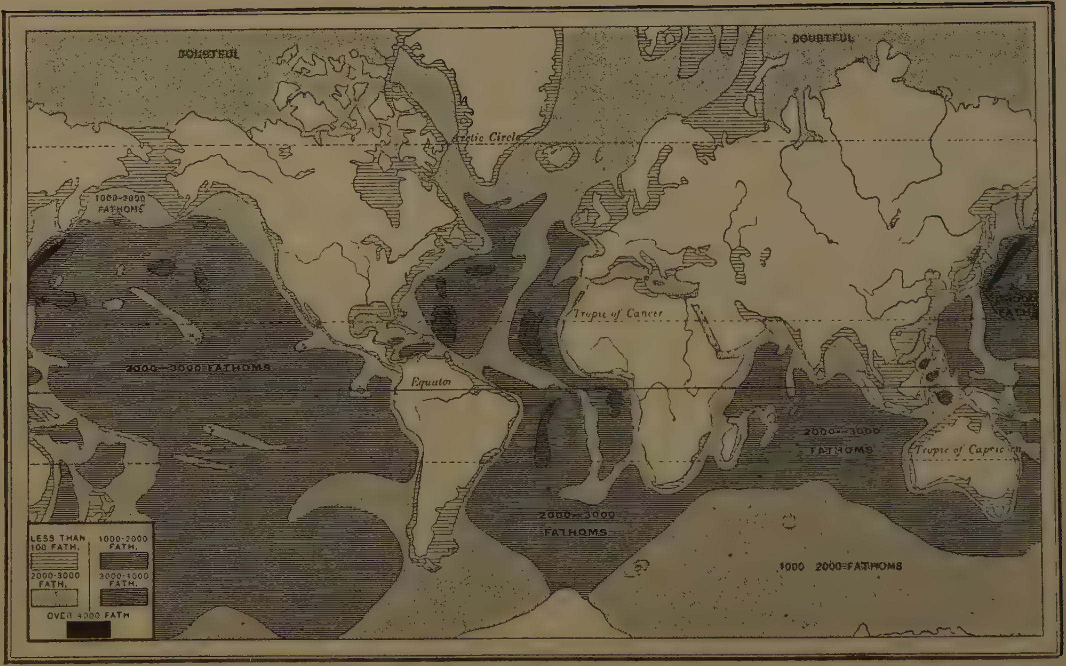

FIG. 46.—Approximate Depths of the Oceans. From *Elementary Physical Geography*. By Ralph S. Tarr (Macmillan and Co.)

unable to draw up its own weight along with that of the lead from great depths, and gives way.

3. No impulse is felt when the lead reaches the bottom, and the line goes running out, and if any attempt be made to stop it, it breaks.

4. In some cases bights of the line seem to be carried along by submarine currents, and in others it is found that the line has been running out by its own weight, and coiling itself up in a tangled mass directly over the lead.

Many patterns of sounding apparatus have been devised with a view of obviating these sources of error, and the student will find an interesting account of them in the work of Sir Wyville Thomson, from which we have quoted. It will be sufficient in this place to describe the "Hydra" apparatus, as it is generally considered the most satisfactory, and was used on the *Challenger* expedition.

The "Hydra" Sounding Machine.—The essential parts are a strong brass tube, *ab*, of about 5½ feet long and 2½ inches in diameter, which unscrews into four chambers. The three lowest of these chambers are closed above by conical valves opening upwards, which do not fit quite tightly, and will thus allow water to pass. The lowest one is closed at the bottom by a butterfly valve, also opening upwards. In the uppermost compartment a piston works, with a piston-rod, *c*, fixed to it, which is continued upwards, and a ring for attaching the sounding line is joined to its upper extremity. The top chamber is provided with a large hole on either side, about the middle of its length, and there is another small hole in the piston itself. A notched tooth projects from the upper part of the axial rod, and can pass through a groove in the arched steel spring as shown in the figure. The spring is so fixed that its two ends are movable up and down the rod. When the spring is forcibly pushed back the tooth projects through the groove. The weight, *d*, consists of several perforated parts, which are made so as to fit into one another and form a compact whole (Fig. 47). Each of these weights is about 1 cwt., and the number of them employed in any particular sounding is decided by the depth it is expected will be reached. The weights are suspended by an iron wire sling, which passes over the notched tooth, which, because the spring has been pushed back, projects through the groove. The weights are sufficient to keep the spring in this position.

When the machine is dropped into the water and let go, it is clear that the piston-rod will be drawn up to the top of the uppermost chamber. As it runs down, water circulates up through the tube and out of the holes in the sides of the top chamber. When it reaches the bottom the weights begin to exert a pull on the piston, and bring it down, but slowly, however, because of the upward pressure of the water in the lower chambers, which only escapes gradually. This enables the weights to drive the projecting chamber *e* into the ground, and, of course, when the weight reaches the floor of the sea, the jerk relieves the spring at the top, and the sling is thrown off the notched tooth. The weights are left behind, and the tube is easily raised with all its valves closed. The chamber, *e*, is full of the material forming the floor and the upper chambers of a sample of water from the bottom.

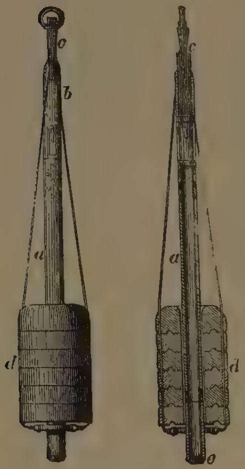

FIG. 47.—The "Hydra" Sounding Machine.

In addition to this sounding machine, other instruments are suitably attached to the line, including, among others, a self-registering thermometer, such as was described in a previous chapter (Chap. III.), and a metal cylinder, a fathom or two above the sounding machine, provided with specially arranged stop-cocks which allow the water to circulate freely while the sounding apparatus is being lowered, but which automatically closes as soon as the return journey is started, enclosing a specimen of water from the bottom of the ocean. One sounding is consequently sufficient to procure at least four important results—the depth, a specimen of the deposit on the floor, the lowest temperature reached, and a portion of the bottom waters.

The reader should revise what has been said in the elementary book about the results obtained with such sounding machines.

Marine Deposits.—The deposits covering the floors of the oceans have been classified in the following way:[1]—

Deep-sea deposits beyond 100 fathoms.	Red clay. Radiolarian ooze. Diatom ooze. Globigerina ooze.	Pelagic deposits formed in deep water far away from land.
	Blue mud. Red mud. Green mud. Volcanic mud. Coral mud.	Terrigenous deposits formed in deep and shallow water close to land masses.
Shallow-water deposits between low-water mark and 100 fathoms.	Sands, gravels, muds, etc.	
Littoral deposits between high- and low-water marks.	Sands, gravels, muds, etc.	

Abysmal Deposits.[2]—These deep-sea deposits cover more than one-half the earth's surface, and gradually shade into the terrigenous deposits enumerated in the above table. There is little or no erosion going on at these great depths, the only disturbing forces of any importance are those connected with submarine volcanic eruptions. On the other hand, chemical changes of a most important kind are continually taking place, resulting in the formation of glauconite, phosphatic and manganese nodules, and zeolites.

Constituents of Deposits.—Essentially these deposits can be considered as made up of (1) the remains of deep-sea organisms, both plant and animal. The former consist of diatoms, while the latter include foraminifera, radiolaria, pteropods, and heteropods ; (2) the products of volcanic eruptions ; (3) secondary products resulting from the decomposition of the second. Doctors Murray and Renard are of opinion that no known deposits occurring among the stratified rocks are identical with the abysmal deposits which are at present found on the floor of the ocean, though they recognise the similarity between some of them and the radiolarian earth of Barbados and radiolarian chert of the south of Scotland.

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[1] J. J. H. Teall, F.R.S., "Deep-Sea Deposits." A review of the work of the *Challenger* Expedition, *Natural Science*, March 1892.

[2] This section has been abstracted from Mr. Teall's paper in *Natural Science*, *op. cit.*, and "Deep-Sea Deposits," by A. Daubrée, *Journal des Savants*, December 1892, and January 1893.

Organic Remains.—Nearly all abysmal deposits contain small amounts of organic matter, and by its decomposition sulphuretted hydrogen is formed. This gas forms sulphides with the metals present, especially with iron, forming sulphides of iron, which occurs notably in the blue muds (p. 141). There is a general absence of the hard parts of more highly developed animals such as crustacea, and also of the bones of fishes. Certain parts of the ear (otoliths) of some mollusca are very common, as well as the teeth and otoliths of fishes and the ear-bones of whales. Some of these remains have been found to belong to species now extinct, but which flourished in Tertiary times. The teeth of sharks are especially abundant. In one haul at a point in the South Pacific fifteen hundred of them were obtained.

The siliceous organisms (Fig. 51) which have been most active in forming extensive deposits are radiolaria and diatoms. Sponge spicules, it is true, are generally found, but they are never present in very large quantities. The species of sponges represented in deeper waters are different from those which flourish in shallower regions.

Mineral Constituents.—Two well-marked groups of mineral constituents *not* formed on the floor of the ocean have been recognised :—(1) Pyroclastic materials, including crystals, crystal fragments, pumice, lapilli, and minute glassy particles ; (2) detrital materials, resulting from the destruction of crystalline schist, crystalline, and epiclastic rocks. The second division is confined to the parts of the ocean neighbouring the continents, and are only found in abysmal deposits where there is a liability to ice-drifts, or in parts across whose surface winds blow from desert regions. The pyroclastic materials are, on the other hand, universally distributed. This is not to be wondered at when the distribution of volcanoes and the force of their eruptions is borne in mind. Submarine volcanoes, too, add to the supply of materials of the kind we are considering. Pumice, which is always abundantly present, occurs in pieces varying in size from that of a mustard seed to that of a man's head. Lapilli and pebble-like fragments of a basic volcanic glass (p. 201) were obtained from many localities, and were always more or less altered. Crystals of olivine, augite, and plagioclase are commonly found in the glassy fragments, and these are usually found associated with manganese nodules, sometimes forming the nuclei of such nodules.

"When the particles which can be extracted from the deep-sea deposits by a magnet are examined under the microscope, a few black and brown spherules may not unfrequently be observed among them. These are supposed to be of *extra-terrestrial* origin." The black ones are usually about one-fifth of a millimetre across, and are composed of an internal metallic part and an external coating of magnetic oxide of iron. With the exception of a slight depression (Fig. 48) these particles are spherical in form. The metallic nucleus has been found to be either iron or this metal alloyed with cobalt and nickel.

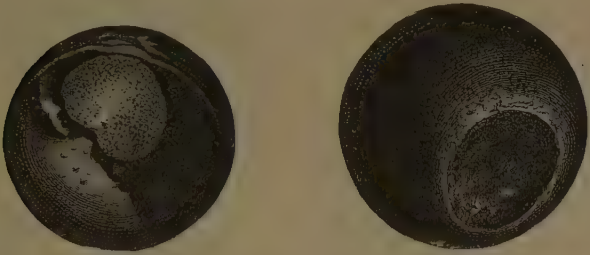

FIG. 48.—Magnetic Spherules.

The brown spherules have an average diameter of half a millimetre. They exhibit a radial and lamellar structure, which has only been otherwise recognised in meteorites. A careful examination has led Murray and Renard to the conclusion that they are composed of a monoclinic pyroxene, containing bluish-brown inclusions like those which occur in hypersthene, which give the spherules their magnetic properties.

"The black and brown spherules were found in the greatest abundance in the red clays of the Central and Southern Pacific. Twenty or thirty black, and five or six brown spherules may usually be obtained from a quart of the clay. Manganese nodules, sharks' teeth, and the ear bones of whales abound in the same localities. In the pelagic deposits of the Central Pacific, other than red clay, magnetic spherules are far less abundant, but a careful search through a large quantity will usually result in the discovery of one or two. These facts clearly point to the conclusion that the spherules are most abundant where the rate of accumulation is slowest."

Chemical Deposits.—These were formed *on* the floor of the ocean where they are found. They may be divided into (1) Clay, (2) Manganese nodules, (3) Glauconite, (4) Phosphate nodules, (5) Zeolites.

Clay.—The argillaceous parts of abysmal deposits are believed to be due mainly to the decomposition of volcanic products, though it is thought a small quantity may be derived from the land.

Manganese nodules.—These concretions vary in size from microscopic particles to large masses of unknown dimensions, and are found in very large quantities in the Atlantic, Indian, and Pacific Oceans. Their common form is that of more or less nodular masses, varying from 1 to 15 centimetres in diameter (Fig. 49). The nuclei are of very various kinds, including fragments of pumice, lapilli, sharks' teeth, ear-bones, sponges, and sometimes even portions of the local deposit. In section, the nodules are seen to be made up of layers concentrically arranged. The layers are differently coloured, the lighter ones containing a larger admixture of clayey matter.

In composition the nodules consist of manganese compounds, notably the hydrate, with hydrated ferric oxide, clay, and other substances. The manganese hydrate is opaque in thin sections, and without crystalline form. In the lighter layers, however, the characteristic dendritic forms have been recognised. Dr. Murray thinks the manganese is chiefly derived from the decomposition of basic volcanic material, while Dr. Renard and Mr. Teall are of opinion that the bulk of the manganese has been obtained in some way from the sea water.

Glauconite.—This mineral "forms an appreciable part of the green sands and muds, and is found as isolated grains in most of the blue muds." Typical grains, which rarely exceed one millimetre in diameter, are always rounded and of a black or dark green colour. Some of them are of a pale green colour, and from their form it is evident they are the casts of foraminifera. The chemical and microscopic characters of glauconite occurring under these conditions are identical with those of the same substance found in the deposits known to the geologist as "greensand." There can be little doubt that in the first instance glauconite is formed "in the hollow spaces of calcareous organic remains, and especially in the interior of the shells of foraminifera."

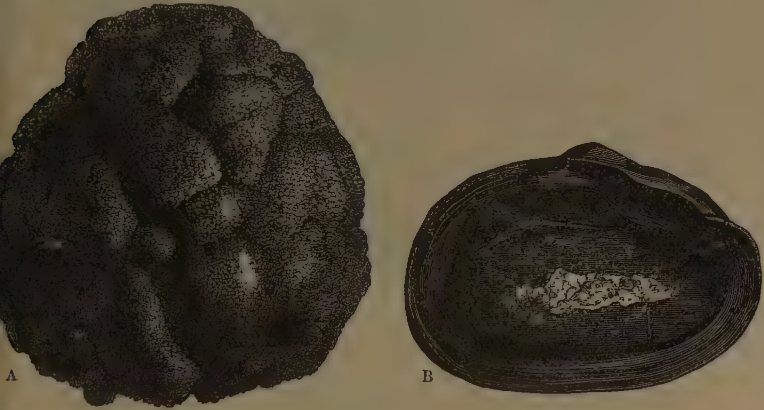

FIG. 49.—Manganese Nodules. (A) Natural; (B) Section.

Phosphate nodules.—These vary in diameter from 1 to 6 centimetres. The composition of the nodules is by no means uniform throughout. The calcium phosphate is present as a cement, binding together grains of glauconite, quartz, and shells of foraminifera, the last named are either filled with or changed into calcium phosphate.

Zeolites.—The minerals known as zeolites are of common occurrence in igneous rocks and are formed from the decomposition of certain silicates such as felspars (p. 188), and nepheline

(p. 190). The member of this class found in abysmal deposits is known as *phillipsite*. There is every reason to believe it has been derived from the alteration of some of the constituents of the fragments of basic volcanic glass and basaltic lapilli, which are, as has been stated, present in these deposits.

DISTRIBUTION AND AVERAGE DEPTH OF CHIEF DEPOSITS.

	Mean depth in fathoms.	Area square miles.
Red clay	2,730	51,500,000
Radiolarian ooze	2,894	2,290,400
Diatom ooze	1,477	10,880,000
Globigerina ooze	1,996	49,520,000
Coral mud	740	2,556,800
Coral sand	176	
Other terrigenous deposits	1,016	16,050,000

Distribution of Abysmal Deposits.—*Red Clay.*—This "is found at the greatest depths and at the greatest distance from land. It is the most widely distributed of all the deep-sea deposits." The mean depth of the places at which it has been found is 2,730 fathoms. The colour of the clay and the amount of pure hydrated aluminium silicate which it contains vary considerably. Sometimes, as in the North Atlantic, it has a brick-red colour, which is due to a thin coating of ferric oxide round its constituent particles. In the South Pacific and Indian Oceans, on the other hand, it assumes a chocolate-brown colour, imparted to it by the presence of rounded grains of manganese dioxide. Red clay is generally smooth and soapy to the touch, though the presence in it of grains of the oxide of manganese, fragments of pumice, and so on, gives it a gritty feeling. The amount of calcium carbonate contained in it varies with the depth. In the deepest parts there is not more than from 1 to 2 per cent., while in the upper portions of the deposit the percentage may reach 20. We have already referred to the great abundance in it of manganese nodules, ear-bones, &c.

Radiolarian Ooze.—This, too, is only found at the greatest depths. In addition to the siliceous remains which give the deposit its name, most of the constituents of red clay are also found. The percentage of actual radiolarian remains varies between wide limits, from 20 to 80 per cent. It is very inte-

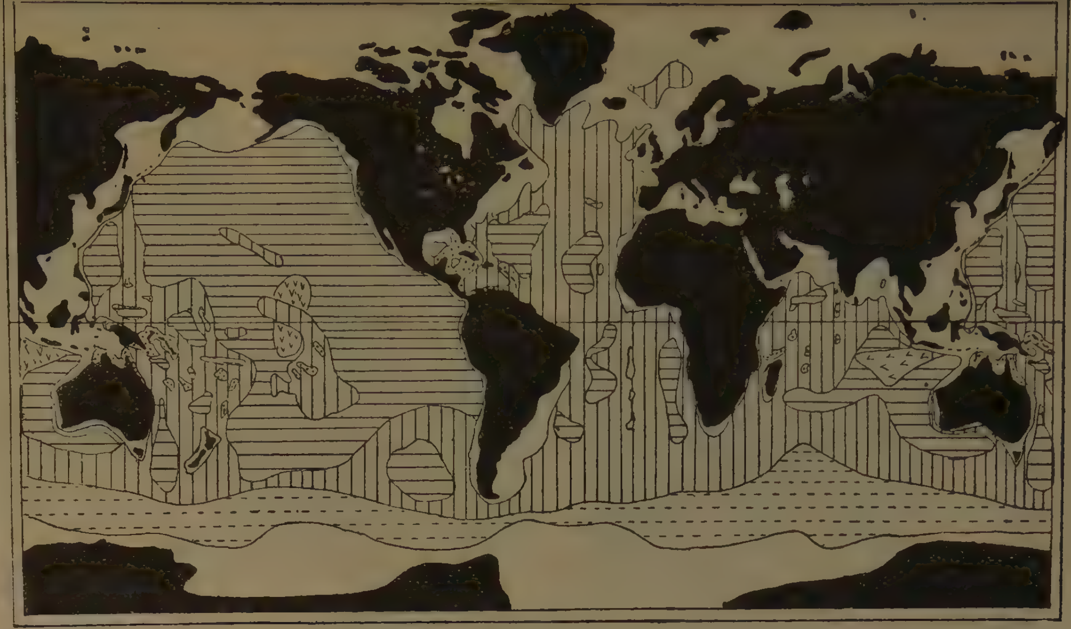

FIG. 50.—Distribution of Oceanic Deposits.—The white space bordering lands marks the region of Terrigenous Deposits; vertical lines mark Globigerina Ooze; horizontal lines mark Red Clay; broken horizontal lines mark Diatom Ooze; two areas indicated thus v v v mark Radiolarian Ooze; dotted spaces mark Coral Sands and Muds; a few small white spaces mark Pteropod Ooze (Reproduced from *Knowledge*).

resting to note that this deposit has not been met with in the Atlantic, but only in the Pacific and Indian Oceans.

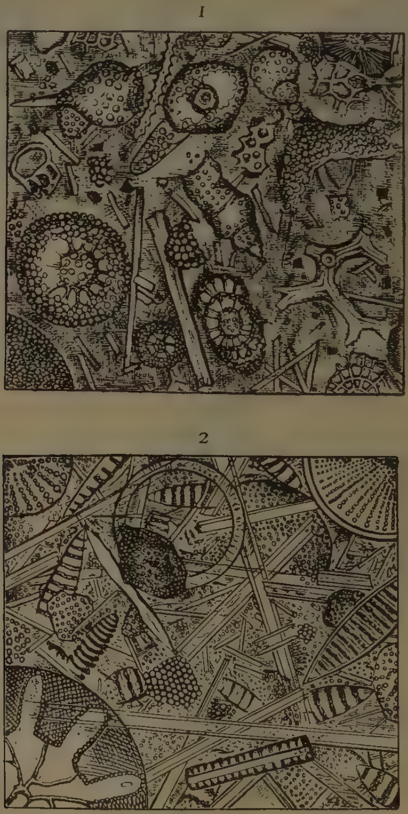

FIG. 51.—Organic Remains in Abysmal Deposits. 1. Radiolarian Ooze, Central Pacific, 4,475 fathoms × 100. 2. Diatom Ooze, Antarctic Ocean, 1,900 fathoms × 200. (*Natural Science*, Vol. VII., Plate III.)

Diatom Ooze was only found by the observers on the *Challenger* within the limits of the Antarctic ice-drift, but other naturalists have found it in the North Pacific. The ooze contains not diatoms only, but also radiolarian remains and sponge spicules. The inorganic constituents which also occur include fragments of granite, gneiss, schists, and other rocks.

Globigerina Ooze.—Doctors Murray and Renard have used this term to include all those deposits which contain as much as 30 per cent. of calcium carbonate composing the skeletons of foraminifera, especially the species *Globigerina*, *Orbulina*, *Pulvinulina*. In addition to these minute shells, those of deep-sea mollusca also occur. Far away from land these oozes contain particles of volcanic glass, and of such minerals as felspar, augite, and hornblende; but nearer land their place is taken by the constituents of the terrigenous deposits into which the globigerina ooze merges.

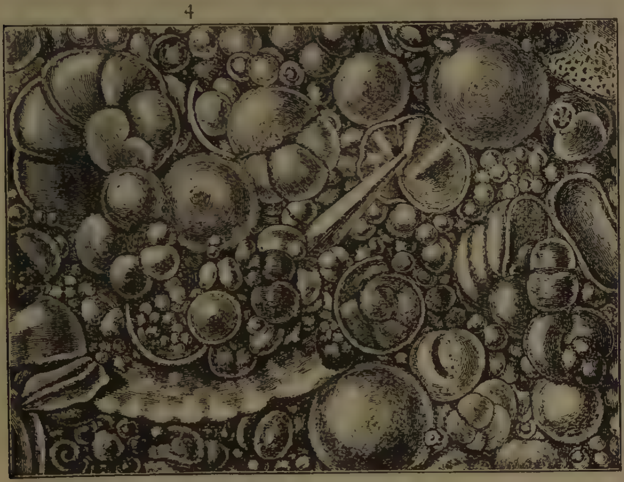

FIG. 52.—Globigerina Ooze, North Atlantic, 1,900 fathoms × 50. (*Natural Science*, Vol. VII., Plate III.)

Distribution of Terrigenous Deposits.—*Blue Mud.*—Blue mud is the most widely distributed. It is only the lower portions of the deposit which possess the characteristic colour, due to the presence of sulphide of iron in a fine state of division, and formed in the manner described on p. 134. When fresh the blue muds smell of sulphuretted hydrogen. The upper layer of the deposit is of reddish-brown colour, in consequence of the ferric oxide and hydrate replacing the sulphide. Quartz grains, which are absent in the abysmal deposits, are of common occurrence in these blue muds; and a great variety of other minerals, (including among many others, felspars, micas, hornblende), has been recognised. Calcium carbonate is always present to some extent, the amount varying from a mere trace up to 35 per cent. Blue muds surround nearly all coasts, and are common in inland seas. Off Brazil, a red mud is found in the place of the more widely distributed blue variety.

Green Muds and Sands.—The colour of these deposits is due to glauconite. They shade on one side into blue muds, on the other into globigerina ooze.

Volcanic Muds and Sands.—These are found in the immediate neighbourhood of volcanic islands. The volcanic materials of which they are composed are mixed with varying amounts of silica and calcium carbonate of organic origin.

Coral Sands and Mud occur in a similar manner round coral islands.

Summary of Distribution.—"Proceeding outwards from the shore, we first meet with the variable deposits of the littoral and shallow-water zones. Banks of sand heaped up under the influence of tidal currents, and wide stretches of mud in the deeper and quieter regions. Here and there occur local accumulations of shells and shelly *débris.* Near the 100-fathom line blue muds are found, and as these are followed down the continental slope, they merge, near its base, into Globigerina ooze—a deposit which extends with wearisome monotony over immense areas. As we descend into the abysses of the ocean, to depths exceeding 2,500 fathoms, the globigerina ooze passes into 'grey ooze, and this again into red clay—the most widely distributed of all the deep-sea deposits."[1]

OCEANIC TEMPERATURES.

Temperature of the Ocean at the Surface.—Oceanographers are indebted to the work of the *Challenger* expedition for the greater part of their knowledge of the temperature of the waters of the oceans both at the surface and at different depths. We shall only call the attention of the student to the salient points of the exhaustive account given in the report of this expedition.[1]

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[1] Teall, *op. cit.*

Regions of Highest Surface Temperature.—The mean annual temperature of the surface of the ocean is illustrated in Dr. Buchan's report by a map showing isothermals for various degrees of temperature; and the examination of these shows that those regions where the temperature reaches 80° F. or more do not form an area which circles the equatorial region of the globe (See Fig. 88). In the Pacific Ocean, for instance, it does not occur between the meridians of longitude 117° W. and 140° W. In the eastern part of the Pacific and in the Atlantic Ocean these high temperature areas lie to the north of the equator. The condition of things in the western portion of the Pacific is quite different, for here the region extends to the east of Australia, as far south as the twentieth parallel of south latitude.

The area under consideration is comparatively contracted in width in the Atlantic, but in the Pacific it has a breadth nearly four times greater. In the Indian Ocean this surface temperature is found over all parts north of latitude 13° S., including the Arabian Sea (except the north-west portion) and the Bay of Bengal. The extent of these regions varies from month to month. In the neighbourhood of the Arabian coast, for instance, the mean monthly temperature of the surface waters is 82°·8 F., whereas in the summer this has fallen to 76°·3, but rises again to 79°·4 in the autumn.

Paths of some other Isothermals.—We have no space for a detailed account of all the isothermals, and shall only give one or two striking facts about their distribution.

The isothermal of 75° F. reaches higher latitudes in the western part of the North Atlantic than anywhere else in the ocean, and this is directly traceable to the prevailing winds which blow from the south and south-west. The isothermal of 45° F. is remarkable for two things: in the first place it extends over a larger number of degrees of latitude than does any other isothermal; and, in the second, it is carried to a lower latitude near Nova Scotia than anywhere else, a fact due to the prevalent north-west winds of the cold months and the cold currents which descend on these coasts from the Arctic regions.

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[1] See *Report of the Voyage of H.M.S. Challenger*, Vol. 50. Appendix of *Physics and Chemistry*, by Dr. Alex. Buchan.

One of the most remarkable facts "in the distribution of temperature of the North Atlantic is the crowding of the isothermals off the coast of America, and their opening out into higher latitudes as they approach Europe, and to lower latitudes as they near Africa." Off the coast of America "the isothermals from 45° to 75° extend over 12 degrees of latitude, but on the eastern side of the Atlantic over 48 degrees." The highest temperature as regards latitude is not near the coast, but in the ocean a considerable distance to the west.

The lowering of temperature off the west coast of all the continents is due to the prevailing winds in these regions passing from higher to lower latitudes. But on the western sides of the oceans, where the prevalent winds, on the contrary, pass from lower into higher latitudes, the temperatures are higher. An exception must, however, be made in the case of the higher latitudes, for here matters are complicated by icebergs, ice-floes, and polar currents.

We must not omit a reference to the marked parallelism ot the isothermals from 40° to 55° F. in the southern hemisphere in latitudes from 40° S. to 60° S.

Temperature of the Ocean at Different Depths.—The mean temperatures for all the oceans at different levels are given by Dr. Buchan in the appendix to the *Challenger* report as follows:—

Depth in fathoms.	Temperature in degrees Fahrenheit.	Depth in fathoms.	Temperature in degrees Fahrenheit.
100	60·7	900	36·8
200	50·1	1000	36·5
300	44·7	1100	36·1
400	41·8	1200	35·8
500	40·1	1300	35·6
600	39·0	1400	35·4
700	38·1	1500	35·3
800	37·3	2200	35·2

We can only give one or two particulars respecting the distribution of temperature at different depths (Fig. 53). The student who desires a complete account of what is at present known on this subject must refer to the splendid series of maps and to interesting explanations of Dr. Buchan which accompany the appendix to which we have called attention and of which we have made free use.

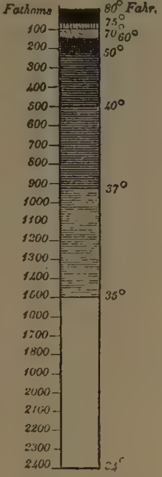

Fig. 53.—Diagram to show the normal decrease of temperature in a column of water in the Ocean at the Equator. From *Elementary Physical Geography*. By Ralph S. Tarr (Macmillan & Co.).

One Hundred Fathoms.—At a depth of 100 fathoms it has been found that the temperature of the western parts of the oceans is considerably higher than the eastern. This difference is the immediate result of the direction in which the ocean currents flow. These, as the student has learnt, are the outcome of the N.E. and S.E. trade winds, which cause them to flow towards the west, carrying the warm surface water with them.

The northern and southern halves of the Atlantic Ocean differ widely in their temperatures at this depth. The part of the South Atlantic where the temperature is above the average value is very much smaller than that of the North Atlantic where the mean temperature is either reached or exceeded. Moreover, while the maximum temperature reached in the South Atlantic at this depth is 63° F., in the northern part of the ocean there is a considerable expanse of water where the temperature exceeds 65° F., and this region encloses two small areas where the thermometer registered 70° F.

The condition of things 100 fathoms below the surface in the Pacific Ocean reverses what we have described as occurring in the Atlantic. In the northern moiety of this ocean a temperature of 70° F. was registered over two small areas only, but in the South Pacific the isothermal 70° F. encloses a very extensive area, over a large portion of which 72° F. is reached. The parts of the Southern Pacific where the temperature is above the average of the whole of the oceans for this depth is larger than those of all the other oceans put together. The lowest readings of the thermometer taken at 100 fathoms below the surface are 29°·0 by the *Challenger* in lat. 65° 42′ S. and long. 79° 49′ E.; and 29°·2 by Dundee whaling vessels off Graham's Land.

It is interesting to note that at this depth in the Pacific Ocean, there is, in equatorial regions, a broad belt of water where the temperature sinks below the mean and in the middle part to 50° F. It extends from Galapagos Islands on one side to the Marshall Islands on the other. Only 18 degrees of latitude to the south the temperature is as high as 72° F., and the proximity of water at temperatures so widely different presents what Dr. Buchan says may be regarded as perhaps the most striking fact of oceanic temperature.

Two Hundred Fathoms.—The mean temperature at this depth has sunk between 10 and 11 degrees under its value at 100 fathoms. It is now 50°·1 F. As was true for a depth of 100 fathoms, so at this distance beneath the surface, the part of the North Atlantic with a temperature higher than the average is more extended than that in the southern portion. Similarly, too, the highest temperature of 64° F. is reached in the northern part, the highest isothermal in the other section being only 55° F.

The distribution of temperature at this depth in the Pacific is similar to that at 100 fathoms. The warm regions of the South Pacific are much wider than those of the northern part of this ocean. In both the Atlantic and Pacific Oceans a higher temperature is found in the eastern part of the equatorial belt; but the increase, as this part of the ocean is approached, is now much less than at 100 fathoms. At the latter depth the increase is as much as 12 degrees, while in the former only about 2 or 3 degrees.

Three and Four Hundred Fathoms.—The higher temperature of the northern part as compared with the southern portion of the Atlantic at a depth of 300 fathoms is even more noticeable than at the previous depths we have considered. The highest isothermal of the South Atlantic is that of 48°, and it covers but a very small area. In the North Atlantic, on the other hand, it covers about one-half of its whole extent, and in two parts of the enclosed area the temperature rises to 60° F., indeed in the more westerly of these the temperature reaches 63°, or 15 degrees in advance of the highest temperature recorded in the

South Atlantic. The highest isothermal at this depth in any of the remaining oceans is 53° F.

The western parts of the Pacific Ocean show an expanse of water which extends through 80 degrees of latitude, where the temperature is above the average value for this depth of all the oceans, viz., 44°·7 F. In the eastern parts of the same ocean the area of high temperature stretches through but 40 degrees of latitude. As at previous depths the highest temperature is found in the western division of the ocean. The two areas of highest temperature at 300 fathoms from the surface are 51° F., about 10 degrees of latitude south of Japan, and 50 degrees the same distance north of New Zealand.

When the depth is increased another 100 fathoms the same general distribution prevails. The excess of temperature in the North Atlantic is even more pronounced. The maximum temperature of the northern half of the Atlantic is 12½ degrees higher than the greatest temperature of the South Atlantic. Similarly the waters of the South Pacific are in some parts as much as 4 degrees warmer than those of the North Pacific.

From Five to Seven Hundred Fathoms.—With the exception of one narrow tongue, which projects to the south, all the waters of the South Atlantic at a depth of 500 fathoms are below the mean temperature of all the oceans at this depth, *i.e.* 40°·1 F. North of the tropic of Cancer the whole of the water of the North Atlantic at a depth of 500 fathoms is above this mean temperature, and the region of the highest thermometer reading *is no longer in the western division of the ocean in the line of drift of the trade winds.* The highest temperature, 54° F., is found just west of Gibraltar. This, for the first time, points to a new source of high temperature. There is a well-marked area of high temperature between New Zealand and Australia, where the water is 4 degrees higher than any in the South Atlantic, and 10 degrees lower than the warmest water of the North Atlantic.

At a depth of 600 fathoms the highest temperature of the North Atlantic still occurs to the west of Gibraltar, where the thermometer reads 51° F. The temperature steadily falls from this maximum to 39° F. off the coast of America. The disposition of the isothermals at this depth establishes the fact of a "warm dense undercurrent which issues from the Mediterranean," and is the source of the remarkably high temperatures of the Atlantic at this depth. In the southern portion of this ocean there is an almost total absence of temperatures above the average. In the Pacific the highest temperatures occur round the Galapagos Islands, and to the north of New Zealand.

Higher temperatures are also found at 700 fathoms to the west of Gibraltar. But at this depth the high temperature area is confined to the eastern part of the ocean. The relative distribution of temperature in the South Atlantic and in the Pacific Oceans remains substantially the same.

From Eight Hundred to Fifteen Hundred Fathoms.—The region to the west of Gibraltar is still, at 800 fathoms, the source of an abnormally high temperature, which is diffused over the Atlantic as far west as longitude 30° W. The distribution of isothermals over the South Atlantic and the Pacific has undergone no material alteration from what we have described for the immediately preceding stratum of water. At 900 fathoms the highest temperature area in the North Atlantic is still in the same position. The South Atlantic temperatures are relatively higher, and in the Pacific there is a marked tendency towards an equalised temperature throughout. At a thousand fathoms the same general distribution holds good. The order of the oceans as regards temperature at this depth is North Atlantic, South Atlantic, South Pacific, and North Pacific, the first named having the highest temperature. At a depth of 1,500 fathoms the north and south divisions of the Atlantic have almost the same temperature, though the western portion has a decidedly lower temperature than the eastern.

LAKES.

Classification of Lakes.—Lakes have been classified in a great variety of ways. Some authorities have divided them into classes according to their mode of formation; others have adopted the plan of arranging them into divisions according to whether they have streams running into or out of them, or both; while others again have based their classes on the situation of the lakes. In view of this diversity of opinion it will be most satisfactory to briefly refer to the classifications of several of these authorities; and since the method of arrangement is one rather of convenience than of vital importance, we shall not presume to express an opinion on the relative values of the methods we describe.

Sir A. Geikie[1] divides lakes into classes depending on the way in which they may have been formed thus. 1. Lakes formed by subterranean movements, as, for example, in mountain-making and in volcanic explosion. 2. Lakes caused by irregularities in the deposition of superficial accumulations prior to the elevation of the land, or, in the northern parts of Europe and America, during the disappearance of the ice-sheet. 3. Lakes caused by the accumulation of a barrier across the channel of a stream, and the consequent ponding back of the water. 4. Lakes resulting from erosion, either that brought about by unequal subaerial weathering or by the prolonged action of glacier ice.

Dr. A. R. Wallace[2] also recognises four kinds of lakes. 1. Lakes of great size situated on plateaus or in central basins. A considerable portion of these plateau lakes are in regions of little rainfall, and many of them have no outlet. 2. Sub-alpine valley lakes, occurring in the lower portions of the valleys which have been the beds of enormous glaciers. 3. Alpine tarns, small lakes occurring at high elevations and very often at the heads of valleys under lofty precipices. 4. Small or large plateau or low-level lakes which occur in enormous numbers in northern Canada, Sweden, Finland, Lapland, and North-west Russia.

The classification adopted by the majority of geographers is in four classes as follows :

1. Lakes possessed neither of an outlet nor an inlet.

2. Lakes possessing an outlet which have no inflowing surface streams.

3. Lakes which have surface streams or rivers running into them but no outflowing ones.

4. Lakes with both inflowing and outflowing surface supplies. The greatest number of lakes belong to this class.

Modes of Origin of Lakes.—For the sake of convenience we shall describe the mode of origin of lakes in the order of the classification given above.

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[1] *Text-book of Geology*, 3rd edition, p. 1087.
[2] Articles in *Fortnightly Review*, Vol. liv, November and December 1893.

The Great Plateau Lakes.—These lakes have been formed by earth movements of the kind described in Chapter XII. The movement of subsidence of the crust took place, of course, after the upheaval of the part of the continent containing the lake basin from below the sea in which it was deposited, as well as after some amount of denudation had taken place. In common with every other kind of lake these are, geologically speaking, modern, for the persistent tendency is for lakes to become silted up. Water would naturally accumulate in such a basin-like depression, for though, as a rule, the rainfall in the districts where they occur is small, since they commonly have no outlet, the greatest cause at work diminishing the amount of water is the evaporation going on at the surface, and the amount supplied by inflowing streams is just about enough to balance the loss from this cause. This condition of equilibrium is in itself conducive to lake formation. An overflow of the water from any part of the hollow would result in the formation of a channel of outlet from which the accumulated drainage would escape.

Lakes of this order are frequent in volcanic districts, and it seems to be almost essential for their formation that a scanty rainfall should be accompanied by great evaporation.

The lakes of Southern Italy, Macedonia, Asia Minor, and perhaps those of Central Africa belong to this class.

Alpine Tarns and Similar Lakes.—The formation of most of the small lakes known as tarns is explained by all geologists as being due to the erosive power of ice. They are mostly true rock basins. In the words of Prof. Bonney,[1] "tarns, universally admitted to be due to glacial action, "occur almost invariably, either at the foot of steep slopes, as in the bed of a corrie on the mountain side, where a somewhat plastic substance like ice would of necessity scrape with considerable force upon the rocky floor below, as the angle of descent was changed; or else behind barriers and narrow places in the bed of the valley over which the ice had been forced, where it would act in a similar way scraping upon the rock behind the obstacle."

Some tarns, however, owe their existence to the cause spoken of in the second division of Sir A. Geikie's classification (p. 149). They are enclosed within mounds and ridges of drift-clay and

[1] *Story of our Planet*, p. 153. Prof. Bonney, F.R.S.

gravel deposited by glaciers which spread over their site at some previous time.

Sub-Alpine Lakes.—These lakes are described by Wallace[1] as "characteristically valley lakes, occurring in the lower portions of the valleys which have been the beds of enormous glaciers, their frequency, their size, and their depth bearing some relation to the form and slope of the valleys and the intensity of the glaciation to which they have been subject." Lakes of this kind are very numerous in all those countries over which, all geologists admit, there was comparatively recently a covering of ice, the traces of which are thrown broadcast in every direction. Wales, Scotland, Switzerland, Scandinavia, and North America all present an abundance of these lakes; and all of these countries, in an increasing degree, have been subjected to glacial action. But there is a most decided difference of opinion as to whether the ice, which all admit existed to great thicknesses, scooped out the basins in which the waters of the lake have accumulated.

Having demonstrated that all the then known causes at work producing lake-basins were insufficient to account for the formation of the numerous examples under consideration, Sir A. Ramsay in 1862 maintained that these were the immediate result of the erosive action of ancient glaciers; and up to the present time his contention is maintained by a group of distinguished geologists who have accumulated more evidence and advanced further reasons for their belief. But Ramsay's explanation is opposed by other authorities, equally eminent, and just as numerous. Space will not permit us to attempt an account of the views of the rival schools of thought. The interested student will find a voluminous bibliography at his disposal if he wishes to form an opinion on the relative values of the opposing theories. The following quotation from Prof. Bonney[2] is, however, indicative of the form of explanation considered more satisfactory by the opponents of the excavation theory. He says these lakes may be regarded as "portions of valleys which had been previously excavated in the usual way during the long period when the Alps were rising and being sculptured; that at a time geologically recent the same forces as had produced the mountain ranges, by wrinkling and doubling into parallel folds a portion of the earth's crust, had again operated, developing a comparatively slight flexure which affected the level of the floors of the valleys. These, at one place, may have been slightly pushed up ; further back they may have curved gently downwards, bending the sloping floor into a hollow, in which water would gradually accumulate as the subsidence progressed."

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[1] *Fortnightly Review*, Vol. liv., 1893, p. 751.

[2] *Ibid.*, p. 153.

Other Ways in which Lakes may be formed.—Some lakes have been formed by the damming of a stream by the accumulation of some form of obstruction in its channel. Such a barrier may be caused by a landslip, by a bank thrown up by the sea across a river's mouth, by a lava stream, or by the passage of a glacier across a valley.

Lake-basins are sometimes eroded by other agents than ice. Atmospheric agencies may cause some rocks to disintegrate at a more rapid rate than those in the neighbourhood, with the result that on the removal of the *débris* there may be a sufficient depression formed to give rise to a lake-basin.

CHIEF POINTS OF CHAPTER VII.

Determination of the Depth of the Ocean.—An ordinary *deep-sea lead* is unsuitable for depths greater than 1,000 fathoms because (1) the weight is not sufficient to carry the line rapidly and vertically to the bottom ; (2) an ordinary sounding line would break with its own weight in addition to that of a very heavy mass ; (3) it is impossible tell when the bottom is reached ; (4) complications arise owing to formation of loops in the line getting carried away by currents. Consequently, an apparatus known as the "Hydra" Sounding Machine has been devised and used with great success.

The Temperature of the Oceans vary (1) according to latitude (from about 80° F. at equator to about 28° F. in Polar regions, in the case of surface water); (2) according to depth (from about 61° F. at 100 fathoms to 35° F. at 2,200 fathoms). The following table shows roughly the temperatures in five latitudes at different depths.

	Latitudes.					
Depths in Fathoms.	3° S	5° N.	23° N.	55° N.	78° N.	
0	78°	78°	73°	57°	32°	Temperatures.
250	48	48	48	46	33	
500	47	47	45	42	33	
1000	38	38	36	35	33	

All water below about 700 fathoms has a temperature less than 40° F.

Classification of Marine Deposits.—

Marine Deposits.

PELAGIC.

(*All formed in very deep water.*)

(*a*) Red clay.
(*b*) Radiolarian ooze.
(*c*) Diatom ooze.
(*d*) Globigerina ooze.

TERRIGENOUS.

(*All formed close to land masses.*)

I. Deep-sea deposits deeper than 100 fathoms.
  (*a*) Blue mud.
  (*b*) Red mud.
  (*c*) Green mud.
  (*d*) Volcanic mud.
  (*e*) Coral.
II. Shallow-water deposits between 100 fathoms and low water.
  (*f*) Sands.
  (*g*) Gravels.
  (*h*) Muds.
III. Littoral deposits between high- and low-water marks.
  (*i*) Sands.
  (*j*) Gravels.
  (*k*) Muds.

Composition of Deposits.—(1) Deep-sea organisms; (2) products of volcanic eruptions; (3) secondary products resulting from decomposition of the first two.

Distribution of Deposits.—As the depth increases we pass in succession littoral and shallow-water deposits of sands and gravels mixed with some mud; after the depth has reached 100 fathoms these give place to the deep-sea terrigenous deposits, consisting of a variety of muds variously coloured in different parts. As we get deeper these muds are in turn displaced by globigerina ooze, which passes into "gray" ooze after 2,500 fathoms, and eventually the widespread red clay takes the place of this.

Classification of Lakes.—Lakes may be classified in several ways; one of the best is the following: (1) lakes formed by subterranean movements; (2) lakes caused by irregularities in the deposition of superficial accumulations; (3) lakes caused by the accumulation of a barrier across the channel of a stream; (4) lakes resulting from erosion.

Mode of Origin of Lakes.—The differences of opinion which are explained in the chapter are not easily summarised. The student must remember that while one school of geological thought attributes a very great part of the work of the formation of lake basins to the eroding power of ice, another equally important school explains it by a reference to earth movements and other causes.

QUESTIONS ON CHAPTER VII.

(1) How are the deposits known as "Diatomaceous ooze" and "Radiolarian ooze" respectively formed?

(2) How has the distribution of temperature in the oceanic waters at different depths been determined? What are the chief sources of error in such observations?

(3) How has the temperature of the deeper parts of the ocean been determined? State what you know of the temperature of the ocean at different depths.

(4) Describe the following:—

(*a*) Globigerina ooze.
(*b*) Radiolarian ooze.
(*c*) Diatomaceous ooze.
(*d*) Red clay.

Stating in each case under what conditions the materials are found.

(5) What are some of the objections to using simply a line with a heavy weight at one end to determine oceanic depths?

(6) Explain the reason of the constant filling up of lakes. State the theories that have been proposed to account for the origin of lakes.

(7) How have the depth of the ocean, the nature of the ocean bottom, and the temperature and chemical composition of ocean-water at different depths been ascertained?

(8) How have samples of ocean-water been obtained from various depths, and in what respects have they been found to differ from one another?

(9) What do you know concerning the waters of the deepest parts of the ocean as regards—

(*a*) Temperature,
(*b*) Density,
(*c*) Composition,
(*d*) The organisms living in them?

(10) Give a general account of the distribution of what are known as abysmal deposits.

(11) What are the distinguishing characteristics of the deposit which occurs at the greatest depths in the ocean?

(12) What do you know of the chemical composition of globigerina ooze? Give as fully as you can the nature of globigerina and its place in the organic world.

(13) What are "manganese nodules," and how have they probably been formed?

(14) Enumerate any oceanic deposits which are composed of silica. How and by what organic forms have such deposits been secreted.

(15) What geological formations have probably existed in a former age as oceanic deposits? Give the evidence on which such a supposition is based.

(16) How have specimens of the substances covering the ocean floor

been obtained? Describe the improvements which have been from time to time effected in sounding apparatus.

(17) Explain briefly the changes which are noticed in the nature of the materials on the ocean floor as we pass from a coast line to mid-ocean. Account for such alterations as well as you can.

(18) Certain of the constituents of the abysmal clays are said to be of extra-terrestial origin. Describe such components both as regards their physical properties and chemical composition.

(19) How is the temperature of the water of the ocean at great depths ascertained?

(20) What do you know of the distribution of temperatures in the surface waters of different latitudes?

(21) Where in the ocean at depths of (*a*) 100 fathoms, (*b*) 200 fathoms, (*c*) 500 fathoms, (*d*) 800 fathoms would you find the warmest water, and where the coldest?

(22) What do you know of the temperature of the water at the bottom of the ocean in different latitudes.

(23) What causes are at work causing modifications of the temperature of the oceanic waters at different depths?

(24) What do you know concerning the marine formations which contain glauconite, and the method of their formation?

CHAPTER VIII

SEAS (*Continued*).—THE TIDES

General Observations.—The most casual observer must have noticed when at the sea side that during every day there are what are known as "two high waters" and two "low waters." The former phenomena he must have heard called "high tides," and the latter, "low tides." Moreover, when the height of the water is on the increase, or when low tide is giving place to high tide, it is customary to speak of the condition of things as a *flood tide*; whereas when the high tide has been reached and the height of the water is becoming gradually lower—as the low tide is approached—we have the state of affairs constituting the *ebb tide.*

But if our imaginary observer is not content with these general observations, and takes notice of the times at which high tide occurs on several successive days, he will be struck with the fact that the time of high tide on any one day is nearly an hour later than on the immediately preceding day. More exactly, the disparity, he will find, is fifty-one minutes, a fact which we hope the reader will take the earliest opportunity of verifying for himself. Thus, if it is high water anywhere, say, at London Bridge or Liverpool, at 6 o'clock to-night, it will be high water at 6.51 p.m. to-morrow. At some places the rise and fall of the water is recorded by means of a tide gauge. The accompanying diagram (Fig. 54) shows the record of a tide gauge at the Queen's Dock, Glasgow for seven successive days.

It will not be long before the student who has commenced such observations as these begins to notice other occurrences which seem, in some way, to be intimately related with the tidal phenomena. He will find that the moon, too, gets minutes later every day, *i.e.*, she rises 51 minutes later, crosses the meridian, or souths, 51 minutes later, and similarly sets the same amount of time later every day. The interval between two successive passages of the moon across the meridian is what is called a lunar day. Its exact length is 24 hours 50 minutes 32 seconds, and in this period there are always two high tides.

These constant coincidences suggest a connection between the moon and the tides; and we shall find as we proceed that there is one of an intimate kind, the nature of which will be fully explained during the course of the chapter.

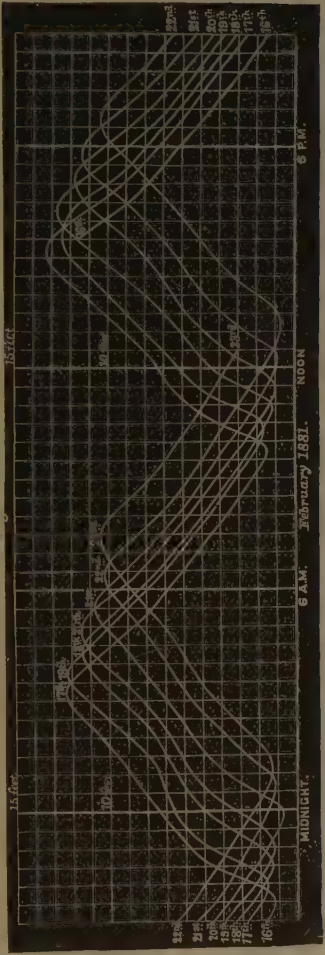

Fig. 54.—Weekly Sheet of Curves Traced by a Tide Gauge. The curves show the periodic rise and fall of the height of water, and also that there are two tides a day. The times of high and low tides are shown to occur later day by day, and the heights of successive high tides are seen daily to change.

Connection between the Moon and the Tides.—Coastguardsmen and others have repeatedly observed that when the shadow of a flagstaff or similar object thrown by moonlight has a certain direction, it is high tide; or, what is the same thing, when it is high tide, the shadow of a fixed object thrown by moonlight always has a particular direction. At London Bridge high water occurs nearly two hours (1 hour 58 minutes) after the moon has crossed the meridian ; so that if the moon is shining and has southed, high water is not far off. We are not always able to see the moon even at night on account of clouds, but the times at which the moon crosses the meridian of London are calculated and tabulated ; and knowing that high water occurs at London Bridge two hours after the moon's southing, navigators are able to find from the tables the exact time of high water there for any day.

At Ipswich, when high water occurs the moon is almost exactly due south ; at London Bridge, when she is nearly south west ; and at Bristol, when our satellite is E.S.E. Such facts as these show at once that there is a connection between the time of high water and the time of the moon's passage across the meridian. The interval between the time at which the moon crosses the meridian of a given place and high water at that place is fairly constant, but it differs in amount for different places. The interval between the time of high water and the immediately preceding meridian passage is known as the *establishment of a port*. The following table shows this interval for a few ports in the British Isles.

ESTABLISHMENT OF PORTS.

	h.	m.		h.	m.
Harwich	0	6	Bristol	7	13
Aberdeen	1	0	Rathlin Island . .	7	56
London Bridge . .	1	58	Yarmouth Roads .	9	15
Whitby	3	45	Holyhead	10	11
Shannon Mouth .	4	0	Pentland Firth . .	11	0
Falmouth	4	57	Dublin	11	12
Swansea Bay . .	6	10	North Foreland .	11	45

The establishments have been selected to show that the interval between the time of high water and the meridian passage of the moon may be next to nothing, or as much as 12 hours. But the tide interval between any two places is constant; hence, knowing the time of high water at any place on a particular day, the time at any other place can be determined.

Tides in the Ocean and in Inland Seas. Range of Tides.—The difference in the height of the water at high and low tides in the open sea is not more than about two or three feet. A few observations only have been made, but these were obtained at oceanic islands. Tides in the Mediterranean sea are so small—only about three or four inches—that they cannot usually be recognised, being obliterated by the effects of wind and other disturbing causes. Similarly, tides in the great North American lakes, in the Caspian and other inland seas are nearly imperceptible. On passing into shallow water, or into a converging gulf, this difference in height, or, as it is commonly called, *the range of the tides*, is increased by the retardation due both to friction and to compression laterally. The crests of the waves thus become crowded together resulting in an augmented range.

Tidal Rivers.—If the channel of a tidal river is of fairly uniform width from its mouth landwards, that is if its width contracts but slowly, the range of the tide decreases on account of friction. In the Thames, for example, the mean range at Sheerness is about twenty feet, at London Bridge about fifteen, at Kew Bridge seven, and at Teddington Lock two feet. The extent of this range is well shown in Fig. 55.

On the other hand, where a river contracts rapidly the tidal range increases from the mouth towards its source. Thus, at the entrance of the Bristol Channel the whole rise at the highest tides is about eighteen feet, at Swansea about thirty, and at Chepstow about fifty feet.

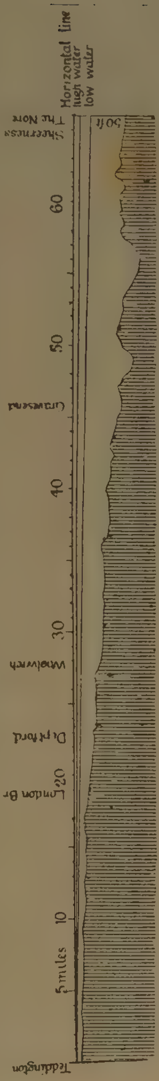

Fig. 55.—To Show how the Tidal Range Decreases in going up the Thames. (From Airy's *Tides and Waves*.)

Bores.—The conditions necessary for the formation of a bore appear to be three in number.

(1) A swiftly flowing river.

(2) An extensive bar of sand, dry at low water, except in certain narrow channels kept open by the outgoing stream.

(3) The estuary into which the river discharges must be funnel-shaped, with its wide mouth open to receive the tidal wave from the ocean. In the Thames only the third of these conditions holds true, and no bore results. In the Severn they are all present, and hence a bore occurs.

Bore of Tsien-tang-Kiang.—In the case of the Tsien-tang-Kiang all three of the conditions pre-eminently obtain. "The range of the tide immediately outside the Hang-chan gulf is twelve feet; but as the wave becomes compressed on advancing towards its head, at the end of the navigable waters, it is as much as twenty-five feet at ordinary spring-tide, and thirty-four feet when the wind is blowing on shore and the moon in perigee at the time of full and change."[1]

Bore of Bay of Fundy.—The tidal waves run squarely between the shores of Nova Scotia on the one side and the States of Maine and New Brunswick on the other, and the narrowing form of the course causes the tides to be exceptionally high. The greatest tide-range in any part of the Bay of Fundy is at Noel Head, in Cobequid Bay, where the difference between high and low water mark reaches fifty-three feet. The Petitcodiac River flows into the head of the bay, and it is on this river that the famous bore is seen. It rushes up the river as a foaming breaker five or six feet high, with a velocity of six or seven miles an hour.

Bore of the Severn.—This well-known bore can be seen very satisfactorily at Newnham. The whole time occupied by the rise of the tide is an hour and a half, and the rise at this place amounts to eighteen feet. The large tide rising with so marked a rapidity produces the bore, which is increased in amount by the fact that the river is here bordered with a great expanse of flat sand near to the level of low water.

How the Moon causes Tides.—We have already seen,[2] that Newton formulated a law which states that every body in nature attracts every other body with a force directly proportional to the product of their masses, and inversely proportional to the square of the distance between them; and the direction of the force is in the line joining the centres of the bodies. It is to this law of gravitation that we must turn for an explanation of the manner in which the tides are caused. In the particular application of Newton's law under consideration the two bodies between which the gravitational stress is set up are the moon and the earth. The earth attracts the moon and the moon attracts the earth. The earth includes two parts of very different physical properties, these are the solid earth and its watery envelope. The former can only move as a whole, but the waters over the earth can move independently. The differing degrees of cohesion of the solid earth and liquid covering cause a very different result to follow from the attractive force of the moon, for while the latter is easily capable of assuming a new shape, the former suffers no such marked deformation.

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[1] *The Bore of the Tsien-tang-Kiang.* By Commander W. W. Moore. Institution Civil Engineers, vol. xcix. 1889.

[2] *Physiography for Beginners*, p. 33.

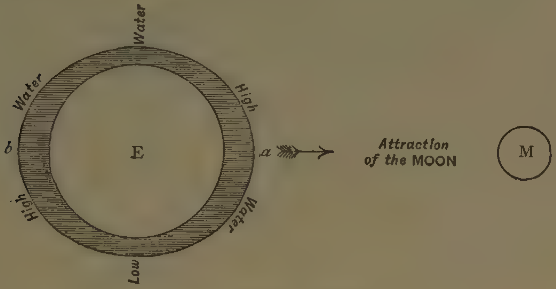

FIG. 56.—The Tide-raising Action of the Moon.

It will simplify our explanation if we first suppose the earth at rest and completely covered by an ocean. Let E in the figure represent the earth under such circumstances and M the Moon. Since the waters at *a* are nearer to the moon than the centre of the earth, (at which point we may regard the whole mass of the solid earth as acting, *a*M is less than EM), and it is apparent from what we have already said that the attraction of the moon at *a* will be greater than at the centre E of the earth. Moreover, as the particles of the water move over one another easily because of its small cohesion, the waters at *a* are pulled up into a heap.

Similarly, the centre E of the earth is nearer to the moon than the point *b*, or EM is less than *b*M, and as a consequence the pulling force at E is greater than at *b*, the result being that the earth E is pulled away from the waters at *b*. The water would thus, under the circumstances, be piled up under the moon and also on the opposite side of the earth and be depressed as a necessary result at right angles to this, that is, at the places marked "low water" in the figure. Such is a very general explanation of what is known as the equilibrium theory of the tides.

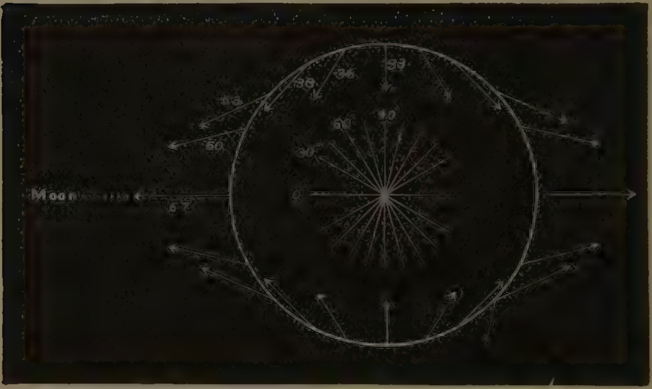

Fig. 57.—The Direction and Relative Intensity of the Tide-generating Force at Various Parts of the Surface of a Planet. (Prof. G. H. Darwin.)

The direction and relative intensity of the tide-generating force exerted by the moon upon the various parts of the surface of the earth is shown in Fig. 57. The action of these attractive forces upon an ocean-covered planet at rest would thus be to pull the waters into a lemon-shaped figure, whose longer axis would point to the centre of the disturbing satellite. Were the earth at rest, or only slowly rotating, as well as being completely covered in the way we have described, the lunar tides would, if there were no friction between the water and the surface of the solid earth, be continually dragged round the earth by the moon's attraction. High tide would consequently occur on any given part of the earth when the moon was on the meridian of that place. But owing to the actual existence of disturbing causes the tides really occur neither directly under the moon nor at the anti-meridian passage, but at various intervals after the moon's meridian passage, and hence we get the establishment of ports.

Differential Nature of the Attraction exerted by the Moon and Sun.—Referring again to our illustration (Fig. 56) the student must clearly understand, before proceeding, that it is not the attraction of the moon for the earth and the waters covering it as a whole which causes the tidal wave. The tide-generating cause is found in the difference between the greater attractive force at *a* and that at the centre of the earth E, on the one hand; and the difference between the greater attractive force at E and that at *b*, on the other. The same important fact holds true for the attractive force exerted by the sun. Moreover, it is for this reason that the moon is a more potent tide producer than the sun. This differential attraction in the case of the moon is more marked than in the case of the sun. The comparison of the differential influence of the moon with that of the sun is interesting as well as important, and we therefore give it at some length.

Comparison of Differential Attraction of Moon and Sun.—Let the unit of length be the radius of the earth.

Then,

Distance of sun from earth's centre = 23,442 terrestrial radii
= 23,442 units of length.
Distance of moon from earth's centre = 60 terrestrial radii
= 60 units of length.

Let the unit of mass be the mass of the earth—

Then,

Mass of sun = 332,000 units of mass
Mass of moon = ·0123 unit of mass.

h(—E—)*f* ··················→59 terrestrial radii ··················→M.

If E in the line above represent the earth, *h* and *f* two points on opposite sides, and M the moon, we have

Differential attraction of moon = M =
= attractive force at *f* − attractive force at *h*.

Applying Newton's law of gravitation,

$$\text{Attractive force} = \frac{\text{mass of moon} \times \text{mass of earth}}{(\text{distance between them})^2}$$

we get,

Differential attraction of moon = M =

$$= \frac{\cdot 0123 \times 1}{(59)^2} - \frac{\cdot 0123 \times 1}{(61)^2}.$$

Because the distance fh = 2 terrestrial radii
= 2 units of length.

Similarly,

Differential attraction of sun = S =

$$= \frac{332{,}000 \times 1}{(23{,}441)^2} - \frac{332{,}000 \times 1}{(23{,}443)^2}.$$

Then,

$$\frac{\text{Differential attraction of sun}}{\text{Differential attraction of moon}} = \frac{S}{M},$$

and

$$\frac{S}{M} = \frac{\frac{332{,}000}{(23{,}441)^2} - \frac{332{,}000}{(23{,}443)^2}}{\frac{\cdot 0123}{(59)^2} - \frac{\cdot 0123}{(61)^2}},$$

from which

$$\frac{S}{M} = \frac{2}{5} \text{ (nearly).}$$

That is to say, the tide-producing effect of the moon is about two and a half times as great as that of the sun.

Spring and Neap Tides.—If the reader has understood the way in which the moon causes the tidal wave, he will probably have surmised that as the relative positions of the sun and earth are at various seasons exactly analogous with those of the moon and earth, the sun, too, ought to produce tides. This is the case. Were there no moon, the effect of the sun's attraction would be similarly felt in the formation of a tide wave, which, as we shall see more fully later, would not be anything like as pronounced as the one caused by the moon. There are thus four sets of tides :—

Lunar Tide.	Solar Tide.
Anti-lunar Tide.	Anti-solar Tide.

The expression anti-tide is used to signify the tide on the side of the earth away from the sun and moon. When the solar tides coincide with the lunar tides, so that the effects are superimposed, we have *Spring Tides*. When the crests of the two tidal waves are as far apart as possible we get *Neap Tides*.

The height of high water and the fall of low water are not always the same. Shortly after new and full moon high water is higher and low water lower than usual. These constitute what we have already referred to as Spring Tides. On the days following the first and last quarters, the difference between the height of high and low water is little more than half as much as at Spring Tides. These tides, where the range is unusally small, are the Neap Tides. As we have observed these monthly variations are due to the combination of the attractions of the moon and sun upon the waters of the ocean. We have, in fact, the following condition of things, which Figs. 58 and 59 make very clear:—

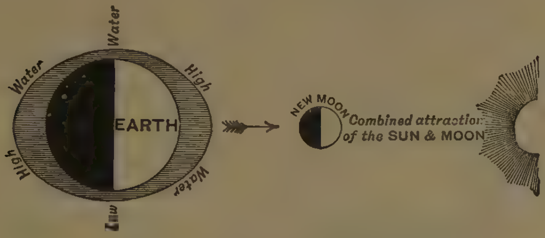

FIG. 58.—Conditions for Spring Tides.

Spring Tide = Lunar tide + Solar tide
= 5 + 2 = 7
Neap Tide = Lunar tide − Solar tide
= 5 − 2 = 3

Other Variations.—The heights of the tides vary with the positions of the sun and moon with reference to the earth's equator, as well as with the distances of these bodies from the earth. The heights are greatest when the sun and moon are nearest the earth and nearest to the plane of the earth's equator.

The highest tides occur when the moon is in perigee (nearest the earth) and near the equator, that is, at the equinoxes, in March and September. The lowest tides occur at the solstices, in June and December, when the sun is farthest away from the equator, and the moon is at its greatest distance from the earth, that is, in apogee, at the same time. The former are the *equinoctial tides*, and the latter the *solstitial tides*.

Around the British Islands the two tides in a day reach practically the same height at any particular place, but in many parts of the world one tide is much higher than the other. This difference is known as *diurnal inequality*, and it is caused by the moon being sometimes north, and sometimes south of the equator.

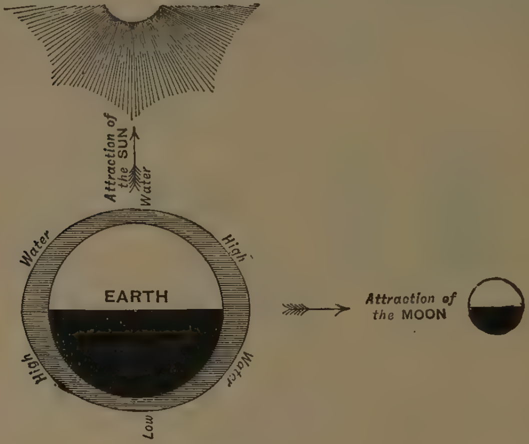

FIG. 59.—Conditions for Neap Tides.

The Nature of Tide Waves.—In our chapter on Wave Motion we have given a general description of the nature of waves in different media, including water waves. We have there seen that a wave motion in water does not imply that the water moves bodily forward in the direction in which the wave is travelling. The water does not move bodily at all, each of its constituent particles goes through the cycle of movements which we have there described. A wave is only the motion of a shape.

As we have seen in the experiment with water in a trough (p. 55) the combination of equal and oppositely moving waves produces a stationary wave. The same thing, too, was shown by experiments described in Chapter IV.

We may thus define tides in the words of Lord Kelvin as "*motions of water upon the earth due to the attractions of the sun and moon.*"

Effects of Wind and Atmospheric Pressure upon Tides.—As is well known the wind produces ripples and waves of every size in the waters of seas and lakes. It also heaps up the water in the direction towards which it blows and drags the water along the surface from one side of the ocean to the other, and so causes currents.[1]

The height of the tide is considerably affected by the wind, and a direct connection has been traced between the force and direction of the wind and the variation in the height of the tides of the British Isles.

Atmospheric pressure also influences the height of the tides. It has been found that a variation of half an inch from the average pressure of the atmosphere causes a difference of fifteen inches in the height of the tide. In those cases, therefore, where the tidal range is small, it is quite possible for changes of atmospheric pressure to completely nullify the tides.

Heights and Breadths of Waves. Comparison of Tidal and Wind Waves.—

Tidal Waves.	*Wind Waves.*
Caused by attraction of sun and moon.	Caused by friction of the wind.
The whole of the ocean water, from surface to bottom, is affected.	Only the water near the surface is affected, and the movement is quite insensible at a depth of 100 feet.
Height in the open ocean about 3 feet.	Height from that of a ripple up to about 60 feet.
Length is half the circumference of the earth.	Length is never more than half a mile.

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[1] See *Physiography for Beginners*, p. 252.

Tidal Waves.	*Wind Waves.*
Theoretical velocity is 1,050 miles per hour. Actual velocity in the Atlantic Ocean is 700 miles per hour.	Velocity is never more than 80 miles per hour, and on the average about 40 miles per hour.
Travel in a constant direction at any particular place.	Travel in all directions.

Co-tidal Lines.—The tidal wave does not travel across the ocean with its theoretical velocity. The varying depths of the water, the friction with the bottom, and other disturbing causes make this impossible. But though its velocity alters from place to place, the time of high tide will be exactly the same at many stations. If we join in all such places where high tide occurs at the same time, we shall cover the map with *co-tidal* lines, which we may define as *lines showing contemporary tides.* The maps of the co-tidal lines of the world (Fig. 60) and of the British Isles (Fig. 61) show the form which these lines take. By means of them we can trace the course of the tidal wave round the world. This path is, owing to the deflections produced by the land masses, by no means as simple and direct as the imaginary tidal wave which we have described as occurring under the theoretical conditions of a water-covered globe. Suppose a parent wave to start at 12 o'clock noon in the middle of the South Pacific. It reaches New Zealand and Kamtchatka about eight hours later, combines with a tide started by the moon in the Indian Ocean, and arrives off South Africa at noon on the following day. Here it combines with the lunar tide raised in the Atlantic, and twelve hours later the wave reaches North America. At about 4 o'clock on the morning of the second day the wave arrives at the British Isles.

Courses of Tidal Waves round the British Islands.—At 5 o'clock in the morning, on the days of new and full moon, the tidal wave which has come up the Atlantic has simultaneously reached the entrance to St. George's Channel in the south and the entrance to the Irish Sea from the North Sea in the north, having been broken into two waves by the Irish Coast. The remainder of the journey can be followed from

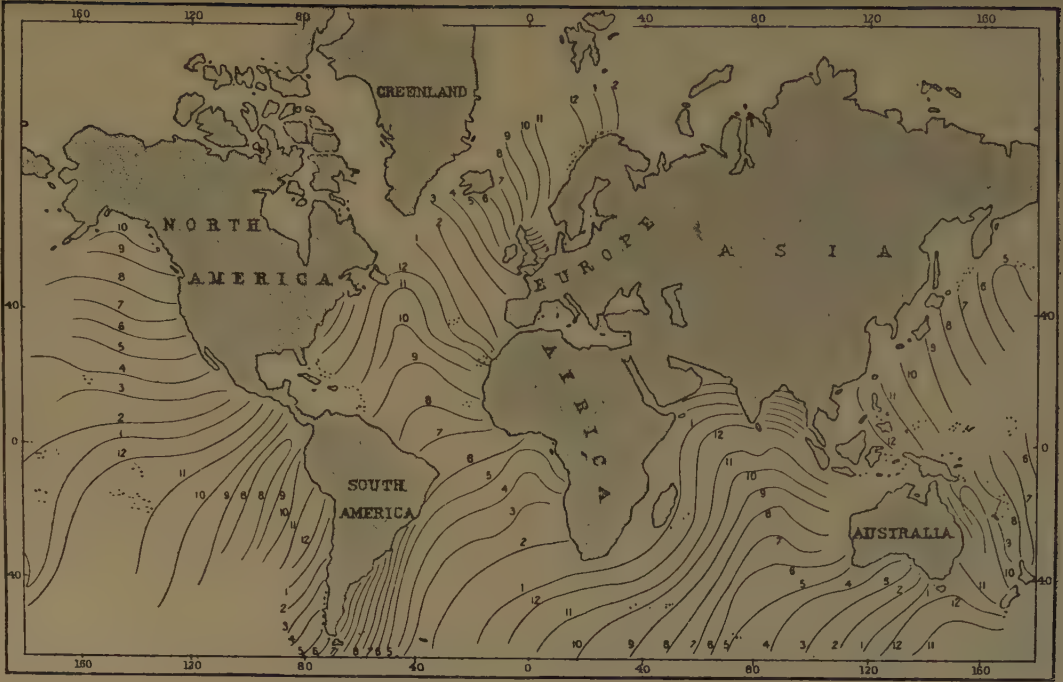

FIG. 60.—Co-tidal Lines of the World. From the *Graphic School Atlas* (George Philip and Son.)

Fig. 61. It will be seen that the two waves approach each other, finally to meet and blend in the middle of the Irish Sea. The part of the course still remaining has thus been described[1]:—

"The velocity of the waves being thus checked, the blended waters are diffused over the flat areas of Morecambe Bay, Solway Firth, and the entrances to the Ribble and Mersey, and there they conspire with the rivers in producing the vast sand banks peculiar to these localities. The same waves also bring high water to the east coast of Ireland. The waters, on leaving, again betake themselves to the entrances of the channels from which they started, and there help to build up another advancing wave, which goes through the same circuit, and so on continually. But all this while the main body of the tide wave has proceeded onwards towards the Arctic regions, the portions we have considered being merely its margins. In like manner, also, the English Channel has been traversed by another branch of the same derivative tide wave, which meets at or near the Straits of Dover another tide wave which has circulated round the north of Scotland and down the North Sea, having started from the main body of the tide in the Atlantic at a period twelve hours earlier."

From what has been said, it will be noticed that when it is high water at the entrances of the Irish Sea, it is low water in the middle of that sea and *vice versa.* Hence the level of the waters oscillates with a kind of sea-saw motion, and at the middle of the sea-saw which crosses St. George's Channel opposite Courtown there is little rise or fall of the tide. This line is called a *nodal line* or *hinge* of the tide. There is another nodal line north of Belfast. Similarly nodal lines occur in the North Sea and in the English Channel.

When, however, we speak of the motion of a tidal wave, it must not be imagined that the mass of water of which the wave is composed has this velocity. The motion of the tidal wave is only a particular instance of undulatory motion, a motion of a form. As we have before insisted, a ship, for instance, floating upon the sea is not carried forward by the progressive waves, but simply rises and falls as they advance and retire.

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[1] *An Elementary Treatise on the Tides.* By James Pearson, M.A.

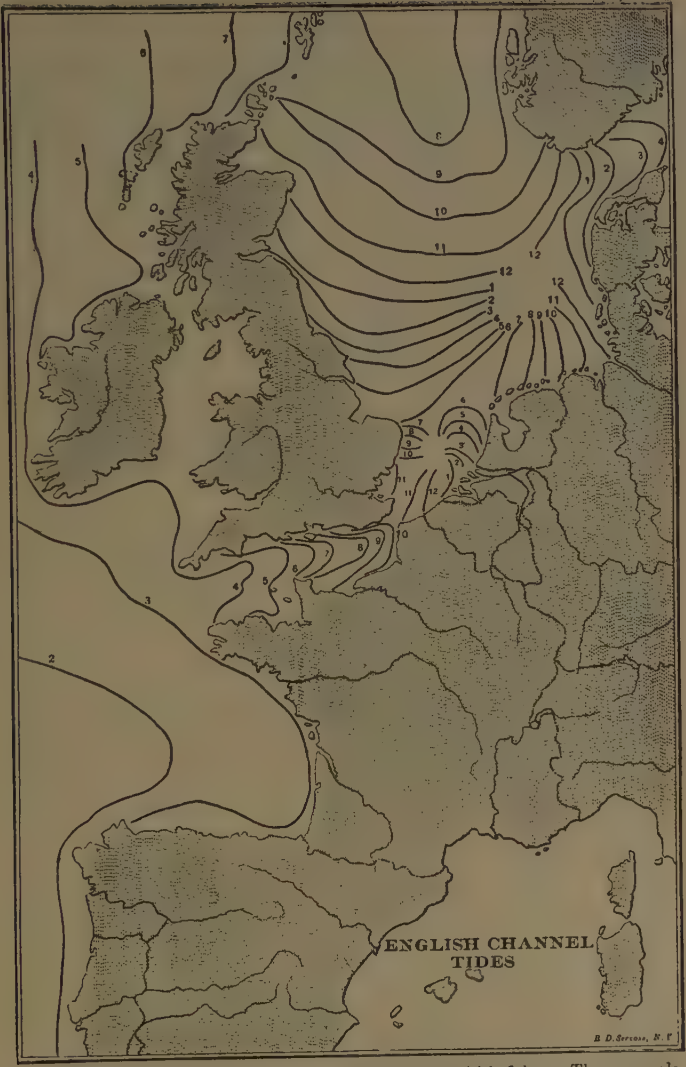

Fig. 61.—The Course of the Tidal Wave near the British Isles. The numerals refer to hours of the day. From *Elementary Physical Geography*, by Ralph S. Tarr. (Macmillan and Co.)

Peculiarities of the Tides of British Isles.—Tides are simpler round these countries than in any other part of the world. There is little diurnal inequality (p. 166) in the height of the tide, and many minor effects which are evidenced in other parts of the world are here insignificant. We have, however, good examples of interference of waves; *e.g.*, on the south coast, in the western part the tide rises about 15 feet, but as it travels eastwards, the range becomes less until about Poole it is 6 feet. Further east, it increases until it reaches a maximum at Hastings, where it is as much as 24 feet and then again diminishes. These results are due to the reflection which the tidal waves undergo by the French coast, so that the main wave coming up the English Channel and this reflected wave interfere with one another. At Portland there is little rise and fall of the water, and this is probably due to the occurrence at this place of a node, or point where two waves destroy one another (see p. 56).

Effects produced on the Motions of the Earth and Moon by Tidal Action.—We have seen that the differential attraction exerted by the moon upon the ocean waters and our solid globe causes a hump of water to exist under the moon and on the opposite side of the earth. If the moon revolved round the earth in the same time that the earth takes to make a complete rotation, the projection would always have the same position. But since the earth rotates under the water pulled into a heap by the moon, a tidal wave is produced. There is thus a drag on the earth as it rotates, which tends to decrease the rotational velocity and therefore to increase the length of the day. Ages ago, the day was only three or four hours long, and the tidal action of the moon has increased it to the present value. In those days the earth and moon were very close together; the revolution of the latter took place in exactly the same time as a rotation of the former, in fact the two bodies moved as if they were rigidly connected face to face. As the day increased in length the month increased also. A condition was eventually reached when the moon revolved once in twenty-nine terrestrial rotations. At the present time the moon revolves round the earth in 27¼ days. The month and the day will in the future tend towards equality of length, and finally will be equal to one another. When this happens the month and the day will be fifty-seven times as long as the day as we now know it. To sum up, by tidal action the velocity of the earth's motion of rotation is being constantly decreased, and the moon's motion is being accelerated. The moon's distance also tends to decrease. The total tendency is to increase the length of the day and the month as we now know them.

General Tennant, in presenting the gold medal of the Royal Astronomical Society to Professor Darwin in 1892, summed up some of the results that had been obtained as to the evolution of worlds by tidal action. Referring to Professor Darwin's memoirs on the subject of tidal evolution, he remarked: "It was shown to be probable that the moon was detached from the earth when the latter had contracted to nearly its present dimensions, and that the present magnitude of the lunar orbit is a direct result of tidal interaction. . . . . Initially the two bodies are rotating as a rigid body: the day and the month are the same: the earth always turns the same face to the moon, and the moon to the earth; and they are nearly, if not quite, in juxtaposition. This configuration, however, being one of maximum energy, is essentially unstable, and the two bodies would gradually separate, the rotations of both being retarded, but that of the smaller much more rapidly than that of the larger. Under certain conditions, indeed, the diminution of rotation of the smaller might so far keep pace with its recession that the habit of always turning the same face to it might be sensibly retained throughout; and in the case of our moon, this habit was probably acquired very early in the history of the earth. But with the present body it would be different. The tides raised in it by the gradually receding satellite would indeed retard its rotation; but for some time the enlarging of the orbit of the satellite would increase its period of revolution much more rapidly, so that the number of days in a month (adopting the specific terms of our own system) would increase from the initial unity, but not indefinitely. After reaching a maximum they would again diminish to unity, and we should ultimately reach a stage when the earth and moon were rotating as a rigid body, but at a considerable distance from each other. The tidal interaction of the two would be exhausted, and the configuration would be now one of minimum energy and therefore stable. From this point their history would be concerned with the action of the sun and other external bodies. . . . Professor Darwin has traced the history of the earth-moon system backwards from its present configuration towards that of maximum energy on the hypothesis of a viscous earth, and he obtains the surprising result that the internal tidal friction of such a viscous earth would be sufficient to explain the present recession of the moon, supposing it to have been separated from an earth of nearly the present dimensions. He calculated the law of change of the day, the month, and the moon's mean distance at the present time, and thus reduced previous concomitant values of the day, the month, and the moon's mean distance. He finds that the number of days in a month, after increasing slightly for a time, diminishes as we go backwards (for one of the most interesting subsidiary results is that our earth and moon have at the present time passed through that configuration referred to above where the number of days in a month is a maximum), and at the same time the distance of the moon decreases. But the important point discovered by Professor Darwin is that when the day is as long as the month the moon has nearly reached the surface of the earth as we know it. The following table shows the course of the changes as we look backward from the present time.

Time in millions of years.	Sidereal day in mean solar hours.	Moon's sidereal period in mean solar days.	Number of days in a month.	Moon's distance in terms of the earth's radius.
0·00	23·93	27·32	27·40	60·4
46·30	15·50	18·62	28·83	46·8
56·60	9·92	8·17	19·77	27·0
56·80	7·83	3·59	11·01	15·6
56·81	6·75	1·58	5·62	9·0
	5·60	0·23	1·00	1·5

"In the table given above the effects of solar tidal friction have been practically neglected soon after leaving the present configuration. For as we go backwards the approach of the moon to the earth would produce a rapid increase of the lunar tides with reference to the solar. But as we approach the limiting configuration it is obvious that, though the tides raised in each body are large, the mutual tidal friction becomes small, and ultimately vanishes when the two bodies rotate as a rigid body. The solar tidal can, therefore, not be neglected near this limiting configuration. On examination it is found that the effects of the solar tide would be slight save at the most remote period. On the whole, the effect of tidal friction would be to retard (looking backwards) the coincidence of the month and day, so that they would not reach equality until each was reduced to about 2 or 2½ hours, instead of 5 hours 36 minutes, and the surfaces of the two bodies would be nearly in contact, instead of there being even the small separation shown in the last line of the table."

Chief Points of Chapter VIII.

Tidal Movements.—Twice a day the waters of the ocean rise and fall in height. Two high tides and two low tides occur in general in the interval between two successive meridian passages of the moon. The length of a lunar day being 24 h. 50 m., the tides are, on the average, 50 m. later every day.

Spring and Neap Tides.—The highest tides occur near the times of new and full moon, and the lowest when the moon is in quadrature. In the former case, the moon and sun act together, and in the latter they act at right angles, so that the high lunar tide corresponds to the low solar tide, and the height of water is the difference between the two effects.

The Establishment of a Port is the interval between the time of high water and the immediately preceding meridian passage of the moon.

The Range of the Tides is the difference between the average height of high and low water; it is small in the open sea, but increases in a converging gulf which opens in the direction of the tidal wave. In a tidal river which contracts rapidly the tidal range increases from the mouth to the source, but if the river narrows slowly the range decreases.

Tides are Waves, and the particles of water do not move bodily, but merely rise and fall in consequence of the attractions of the sun and moon. Around the coast of the British Isles are several places, *e.g.*, Portland, where the tidal range is very small on account of waves interfering with one another.

Tides of the British Isles.—The tidal wave from the Atlantic is broken into two by the Irish coast, and the two waves meet in the middle of the Irish Sea. A wave which goes up the English Channel is met near the Straits of Dover by another wave which has been round the north of Scotland, and down the North Sea. This wave is 12 hours older than the one it meets.

Co-Tidal Lines show contemporary tides, or places where high tide occurs at the same hour.

Tidal Bores are produced by the tidal wave meeting a swiftly-flowing river discharging into a funnel-shaped estuary with wide mouth. Great tidal bores occur on the Tsien-tang-Kiang, in the Bay of Fundy, and on the Severn.

QUESTIONS ON CHAPTER VIII.

(1) The sun's attraction at the earth's surface is much greater than that of the moon, yet the moon is the more important agent in producing tides. State the exact reason of this.

(2) Give an account of Professor George Darwin's researches on the effects produced on the motions of the earth and moon by tidal action.

(3) What is the difference between spring tides and neap tides? What determines the time of the occurrence of spring tides and neap tides?

(4) State why the moon's influence is greater than that of the sun in causing the tides.

(5) Describe the causes of the tides.

(6) What facts show that the moon is chiefly responsible for the tides?

(7) Describe some simple observations which point to a connection between the moon and the tides.

(8) Explain what is meant by "the establishment of a port."

The establishment at Aberdeen is 1 h. and at Bristol 7 h. 13 m. If high water occurs at 2.30 o'clock at Aberdeen, what time will it occur at Bristol?

(9) How could you find the time of high water at London Bridge if you were given a table showing when the moon was on the meridian, and you knew that the "establishment" at London Bridge was 1 h. 58 m.?

(10) Compare tidal waves with wind waves.

(11) Describe in general terms the course of the tidal waves around the British Isles.

(12) Mention some peculiarities of tidal range along the south coast, and explain briefly their cause.

(13) Define range of tide, and mention a place in the British Isles where the range is small and one where it is large.

(14) What is a tidal bore, and what are the conditions which lead to its production?

(15) Show, by numerical means, that the tide-raising action of the moon is greater than that of the sun.

(16) How is it that there are, in general, *two* high waters and *two* low waters in a day?

CHAPTER IX

THE EARTH'S CRUST

ROCK-FORMING MINERALS

Introduction.—The study of the earth's crust can be pursued from many points of view, but it will be most convenient for our purpose to commence with an examination of the materials of which it is composed. The most cursory inspection will convince the student that these materials differ widely in character from place to place. In one district he may find that immediately beneath the soil there occurs a great stretch of sandstone, in another the subjacent material is clay, or in a third locality chalk may occupy a similar position. All these substances and many others are referred to by the geologist under the general term *rock*. This expression includes all those materials which help to build up the earth's crust; and whether they be hard or soft, compact or powdery, it matters not to him. In this wide sense the term "rock" includes materials of such varying hardness and compactness as sand, mud, chalk, granite. Subjected to a closer examination, rocks are soon found to be complex in their composition. They are aggregates of other simpler substances to which the name *mineral* has been given. To the mineralogist *a mineral is a natural substance with a fairly definite chemical composition which does not vary from part to part of its mass, and which was formed without the help of animals or plants.* Thus in the case of some pieces of granite which we have cited as an instance of a rock, we can easily distinguish three minerals present in it, viz., quartz, orthoclase, and muscovite, with which constituents we shall deal more fully later. In the hands of the chemist, however, minerals can, with a few exceptions known as native elements, be resolved into still simpler substances, *chemical elements;* but from the geologist's standpoint the structure and composition of a rock is satisfactorily explained when he can enumerate the minerals of which it is composed and the manner in which these are arranged. Finally, it must be remarked that the general tendency of modern chemistry is to show that the chemical elements themselves are all allotropic forms of one simple form of matter, the molecules of which are arranged differently to make what we now recognise as elements.

Minerals.—A complete study of minerals constitutes the science of Mineralogy; but with the object of becoming acquainted with the composition and properties of the commonest rock-forming minerals it will only be necessary for us, in this place, to become acquainted with the general method of describing a mineral, and to apply this knowledge to the description of these common minerals which we must regard as the bricks with which the great rock masses are built. To fully describe a mineral we must give an account of all its characteristic properties, which description will include such facts as the shape and form of its crystals, if it is crystalline, *i.e.*, not only its crystalline system but information as to whether the crystals are long or short, stout or slender, whether they form thick or thin tablets, and so on; or the surface of the crystal may require a word of description as to whether it is rough or smooth, plane or curved, etc. Sometimes instead of assuming a definite crystalline shape it is found having indeterminate forms, like, *e.g.*, stalactites of calcite, or nodules of malachite. The colour, lustre, hardness,[1] specific gravity,[1] touch, smell, taste, all assist the mineralogist in distinguishing one mineral from another, but these properties are not equally valuable. While hardness and specific gravity are fairly constant for a given mineral, its colour may, owing to the presence of small amounts of impurity, vary between very wide limits. There are many other characters which sometimes assist in the recognition of a mineral, which, though important and interesting to the mineralogist, are not immediately valuable to us. We are particularly concerned with those properties of a mineral which enable us to recognise their presence in rocks, and these the reader will best become familiar with by a careful study of the descriptions we shall proceed to give of those minerals which are most abundantly present in the chief rocks of the earth's crust. In recent years a great advance in the study of rocks has been made by their examination in thin slices under the microscope. The behaviour of minerals under these circumstances is described by reference to another set of properties altogether, and we shall also have to become familiar with the leading facts in connection with this method of examination.

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[1] See *Physiography for Beginners*, pp. 9 and 23.

Crystallography.—Crystals are described by reference to six systems, which are distinguished from one another by the way in which the axes, or imaginary lines round which the crystal is built up, are arranged. These systems are usually named as follows—

1. Cubic
2. Tetragonal
3. Rhombic
4. Hexagonal
5. Monoclinic
6. Triclinic

1. *Cubic.*—Crystals belonging to this system have three axes of equal length, all intersecting at right angles to one another. The simplest solids belonging to this system are the cube with six faces (Fig. 62, No. 1) and the octahedron (Fig. 62, No. 2) with eight. Common salt and fluor-spar both commonly occur in cubes and the diamond in octahedra.

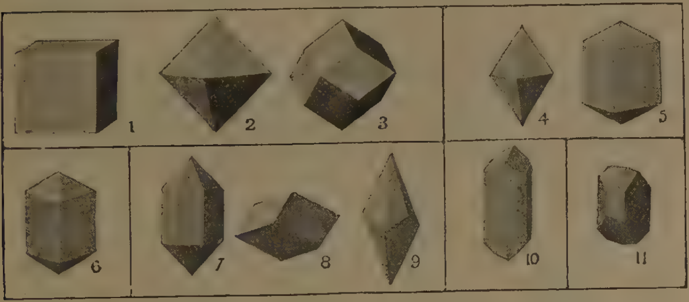

FIG. 62.—The Crystallographic Systems. 1, 2, 3, Cubic; 4, 5, Tetragonal; 6, Rhombic; 7, 8, 9, Hexagonal; 10, Monoclinic; 11, Triclinic. (After Geikie.)

2. *Tetragonal.*—In this system, too, there are three axes all at right angles to one another; but instead of being of equal length, one (the principal or vertical axis) is either shorter or longer than the other two lateral axes, which are of the same length. Fig. 62, Nos. 4 and 5, shows a tetragonal prism and a tetragonal pyramid. The number of crystals belonging to this system is not so great as in the other cases, but we can instance rutile and cassiterite as typical examples.

3. *Rhombic.*—The axes of the rhombic system are all at right angles to one another, but they are all of them of different lengths. We shall consequently have forms analogous to those of the preceding system known by such names as rhombic prism and rhombic octahedron. Fig. 62, No. 6, is an example of a rhombic prism. Hypersthene, enstatite, and bronzite, which we shall describe under the ferro-magnesian silicates, all crystallise in this system.

4. *Hexagonal.*—This system is distinguished from the others by its possession of four axes. Three of them, the lateral axes, are of equal lengths, and are inclined to another at angles of 60°, and all of them intersect the fourth, or vertical axis, at right angles. Fig. 62, Nos. 7, 8, 9, shows some typical hexagonal crystals. Quartz and calcite are two common minerals which crystallise in this system.

5. *Monoclinic.*—The three axes of this system are of unequal lengths. Regarding one of them as the principal axis, it is found that while one of the remaining lateral axes is at right angles to the principal axis, the other is inclined to it obliquely. Fig. 62, No. 10, shows a crystal of augite which can be taken as a typical monoclinic crystal.

6. *Triclinic.*—The axes, of which there are three, are of unequal lengths, and all intersect at angles which are not right angles. It is the least symmetrical of all the systems. Fig. 62, No. 11, exhibits a crystal of albite (p. 179), which shows the general characters of crystals of this system very well.

Examination of Minerals before the Blowpipe.—The behaviour of minerals before the blowpipe, a simple instrument with which we shall assume our reader to be familiar, provides the mineralogist with an excellent means of recognising them. Some of the more important facts observed in this process of identification are as follows: (1) its fusibility, (2) the colour the mineral imparts to the flame, (3) the colour which it gives to a borax bead, (4) the changes it undergoes when heated in a glass tube closed at one end, (5) its behaviour when heated on charcoal. We shall briefly describe each of these reactions.

Fusibility.—To test the fusibility, *i.e.*, the ease or difficulty with which a mineral melts, it is sufficient to hold a small splinter of it in a loop of platinum wire, and to test whether it will melt in the ordinary flame of a laboratory burner, and, if so, whether the melting is noticed with large or small lumps. If it is infusible under this degree of heating, it is tried in the blowpipe flame, and the extent to which melting occurs is noticed. A scale of fusibilities has been arranged by von Kobell, and is very commonly used.

EXPT. 23.—Try the fusibility of any minerals accessible in the manner described above.

Flame Colouration.—Certain metallic salts are easily volatilised, and the volatile product has the power of imparting a characteristic colour to the flame of a Bunsen burner. As a rule, the chlorides of the metals are the most volatile, and it is consequently customary to moisten the mineral or salt to be experimented upon with hydrochloric acid. A little of the substance so moistened is then picked up by a loop on clean platinum wire, and introduced into the lower part of the flame. Any colouration which is produced will be most marked round the upper edges of the flame, and is best observed by holding something black behind the flame. The most easily recognised flames are those due to sodium compounds, which give rise to a golden-yellow colouration; potassium compounds to a violet, which is, however, easily masked by the presence of sodium, and it is customary to view the flame through a piece of blue glass, which absorbs the colour due to sodium, and transmits that caused by the potassium compounds. Copper compounds, as a rule, give an emerald-green colour to the flame, but the chloride a bright blue. Strontium and lithium both produce crimson flames, but that of the former has a yellower tinge. Other substances also colour the flame, but we must refer the reader to books on Mineralogy for a fuller account of this subject. It is at once clear that any mineral which gives rise to one of the well-marked flame colourations must have in its composition the element which causes such a colour.

EXPT. 24.—Procure specimens of common salt, nitre, copper sulphate, strontium nitrate, and use them to colour the flame of a laboratory burner in the manner described. Be careful to clean the platinum wire after each experiment by dipping it into a test tube of dilute hydrochloric acid and holding it in the flame, repeating the operation until no colour is given to the flame.

Examination on Borax Beads.—When borax is heated before the blowpipe it swells, gives up its water of crystallisation, and fuses to a clear transparent glass.

Expt. 25.—Make a circular loop on a clean piece of platinum wire. Shake some powdered borax into a watch glass. Heat the loop in the blowpipe flame, and plunge it, while hot, into the borax. A quantity of borax adheres to the hot wire; heat this again, and watch the formation of the borax bead.

If a small piece of certain metallic oxides is introduced into such a bead, and the bead is heated strongly, it is found that the oxide dissolves in the glass, and colours it in a characteristic manner. The colour often alters in different parts of the blowpipe flame; and it is usual to distinguish two parts of the flame, viz., the outer oxidising zone and the inner reducing zone. In speaking of the colour any substance gives to a borax bead, therefore, we must always specify the flame in which it has been heated. Here, again, we must refer to some work on Mineralogy for detailed information as to the colours produced by different oxides.

Expt. 26.—Heat a little copper oxide, or any compound of copper which is convenient, on a borax bead, first in the outer zone, and note that the bead is green while hot, and changes to blue when cold. Then heat the same bead in the inner flame for some minutes, and notice that the blue colour gives place to a dull red, due to metallic copper. If there is any difficulty in producing the change of colour, introduce a minute fragment of metallic tin, which will at once, by aiding the reducing power of the flame, cause the change to take place.

Changes produced by Heating in a Closed Glass Tube.—In this examination, small tubes of hard glass with a bulb on the end are used. The fragment of mineral is dropped into the bulb without soiling the tube, which must be of such a length that the upper parts may be cold while the bulb is quite hot. The observations consist in noticing whether there is any evolution of gas or any formation of a sublimate. A sublimate is formed by the volatilisation of the mineral or part of it, and the subsequent condensation of the vapour on the cold upper parts of the tube.

Expt. 27.—In such a bulb as above described heat a little red oxide of mercury and notice the evolution of oxygen and the sublimate of metallic mercury. In a second tube heat a fragment of iron pyrites, and observe the sublimate of sulphur.

Examination on Charcoal.—Several experiments are made with the mineral on charcoal. It is usual, however, to first heat it in the oxidising flame. A fragment of the mineral is placed in a hole scooped out of the charcoal, and heated by directing the flame over the fragment to the charcoal beyond. After this heating has been continued for some little time, it may be noticed that an incrustation has been formed on the cold part of the charcoal just beyond the portion heated by the flame. These can often be recognised by their colour ; thus compounds of zinc give an incrustation which is yellow when hot and white when cold. In the case of white incrustations it is the custom to drop a little cobalt nitrate solution upon it, and to again strongly heat in the outer flame for four or five minutes, when in some cases it is found that the incrustation has become permanently coloured. For instance, had the zinc incrustation mentioned above been so treated, it would be found to have assumed a bluish-green hue.

EXPT. 28.—Perform the experiment of heating a little zinc sulphate on charcoal, or the mineral zinc blende will do, in the manner described. Moisten the incrustation formed with cobalt nitrate, and heat strongly again. Notice that it becomes bluish-green.

Many minerals which contain the heavy metals when heated on charcoal in the inner reducing flame are reduced to the metallic condition. Others only yield a metal when heated in this manner with sodium carbonate, which by its easy fusibility assists the reaction very much. In some cases the globules of metal are easily recognised in the melted sodium carbonate ; in other cases it is necessary when it is cold to scrape off the residue in which no metallic globules have been recognised, and to powder it in a mortar and add water. The fine particles of carbon are washed off, and the flattened metallic globules are seen on the sides of the mortar.

EXPT. 29.—Heat a piece of galena, or a little red lead, on charcoal, in the inner reducing flame, and notice the formation of the globules of metallic lead.

Examination of Minerals under the Microscope.

The Microscope. — The instrument used in examining minerals differs in one or two important respects from an ordinary microscope. The stage is carefully graduated in degrees, etc., and is provided with a vernier, so that its position may be defined with greater accuracy. It is provided with two

Nicol's prisms;[1] one, called the *polariser*, is arranged on a swinging arm below the stage; the other, known as the *analyser*, is carried by a brass slide which can be pushed in and out of the tube in which it is arranged above the objective. Fig. 63 shows a simple petrological microscope, and an examination of it will give a better idea of its construction than any amount of verbal description.

The Preparation of Rock Sections.—Though isolated minerals are sometimes subjected to microscopic examination it is usually when they are aggregated together to form rocks that this mode of inspection is resorted to. A slice is first cut from the rock by means of a lapidary's wheel, which is, however, only possible when the rock is possessed of some degree of compactness and hardness. One face of the slice is then ground quite smooth and flat by means of emery powder, emery flour, rouge and a water of Ayr stone in succession. It is then attached by means of Canada balsam to a piece of glass, and the other side of the slice treated to the same process of grinding and polishing until it is thin enough to be transparent. The thin slice is then covered with a very thin piece of glass, which is also glued on with Canada balsam, and the rock section is ready for microscopic examination.

Characters of Minerals observed under the Microscope.—We can only pretend to give the roughest outline of the examination of the constituent minerals of a rock section under the microscope. The petrologist takes note, amongst other things, of the *external contour or form* of a mineral. Sometimes, though by no means always, the mineral is found to be bounded by clearly defined sides, giving it a well-marked shape, which can often be recognised as a section of some well-known crystalline form. In determining the form it is often very desirable to determine the angle between adjacent faces, and for this purpose the rotating stage and the cross wires with which the eyepiece is provided are used.

Other marked characters which assist in the determination of a mineral under the microscope, and which are spoken of as *internal* characters, are *cleavage cracks* and *enclosures* when they occur. Cleavage cracks are as a rule recognised without

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[1] A description of the construction of Nicol's prism from a rhomb of calcite will be found in any book on Optics.

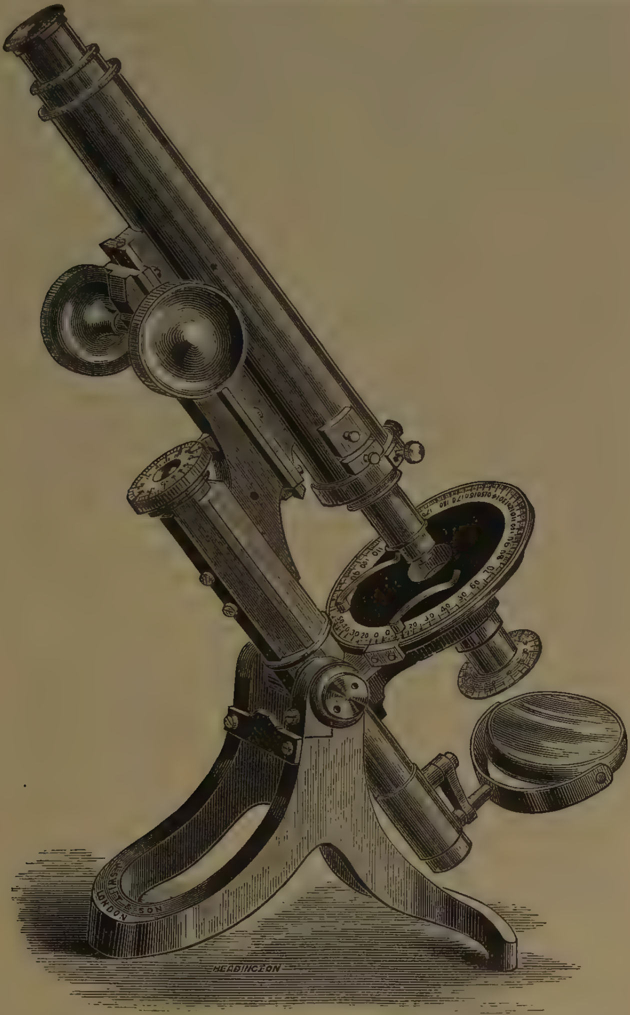

FIG. 63.—A Petrological Microscope. [The type of instrument made for students by Messrs. Swift and Son.]

much difficulty, for it is generally along them that decomposition begins. While some minerals like quartz never show these cracks, others like muscovite have them very well developed. The parallel cleavage lines along the crystals of muscovite shown in the section of granite in Fig. 66 represent the intersection of the plane of the section with the planes along which the crystal would split into plates in the manner which, as we shall see (p. 190), is characteristic of muscovite. These cleavage cracks often afford a means of distinguishing between two minerals which are very similar in appearance under the microscope, like epidote and pyroxene, the cleavage in the former case being always more marked than in the latter.

Enclosures are often found within a mineral when it is examined under the microscope, arranged either in zones, at the centre of the crystal, or round its edges. The inclusions themselves may be of several kinds, viz., gaseous, liquid, glassy, or mineral. Gaseous enclosures are found on examination to be either of air or carbon dioxide contained in a cavity which often reproduces the shape of the enclosing crystal. The liquid material found may be one of many which occur, such as water, liquid carbon dioxide, or saturated solutions of various salts. That such solutions are often saturated is proved by the presence in them of crystals of the dissolved salt, thus perfect cubes of sodium chloride held in suspension in the liquid filling the cavity have sometimes been recognised. Fragments of glass are often abundantly present, and their character is determined by their behaviour under polarised light.[1] Mineral inclusions are most frequently of some definite shape, taking the form of perfect needles it may be, or rods, scales, etc.

We have said that these enclosures often occur in zones along lines which reproduce the shape of the crystal containing them, but this is not the only cause bringing about a zoned structure. There is often other evidence of the gradual building up of the crystal by depositions upon the outside. The separate layers often have different indices of refraction, and hence become apparent by their differing optical behaviour.

Besides these properties which we have now briefly described, and which will serve as examples of the points noticed in the microscopic examination of a rock section, there are many optical characters of the highest value to the petrologist which we have no space to describe, but which the interested student will find fully explained in works on Petrology.[1]

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[1] The reader must consult books on Optics or Mineralogy for a further treatment of this subject.

Classification of Minerals.—We must now proceed to an account of the commonest rock-forming minerals. They can be classified in many ways. For instance, if the mineral was formed at the same time or after the rock in which it is found, it is said to be *authigenic*, while if it is older than the rock containing it, it is spoken of as *allogenic*. Or, we may divide minerals into *essential* and *accessory*, meaning by the former those[2] "whose presence is implied in the definition of a rock," and by the latter all minerals "whose presence or absence does not sensibly affect the character of a rock." A further division into *original* and *secondary* is very common. Original minerals include both those which existed before the rock they help to build up, and those formed contemporaneously with it. Secondary minerals, on the other hand, result either from the alteration or reconstruction of original minerals, which may be brought about in several ways, as we shall describe later. We shall first refer to the essential rock-forming minerals, and then have to content ourselves with a mere mention of some of the remaining accessory ones.

ESSENTIAL ROCK-FORMING MINERALS.

The chief of these have been already described in our elementary book, to which the reader should make reference. In enumerating them we shall only attempt to supplement the description which has been there given, utilising the information which has been brought before the student in this chapter.

Quartz is one of the crystalline forms assumed by the most abundant binary compound in the earth's crust, viz., silica, or silicon dioxide (Fig. 64). It crystallises in the hexagonal system (p. 180), and often occurs as a hexagonal prism capped by a hexagonal pyramid. It is too hard to be scratched by a knife, and is usually colourless. In rock sections it is generally allotriomorphic in form (*i.e.*, having no definite shape, its form being decided by the neighbouring crystals), shows no cleavage cracks, and exhibits many enclosures, which are generally liquid or glassy. It is quite clear under the microscope, showing no decomposition products.

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[1] Prof. Cole's *Aids to Practical Geology*, Chapter xvi.

[2] *Text-book of Petrology*, Dr. F. H. Hatch, to which the student should refer for a fuller account of the whole subject.

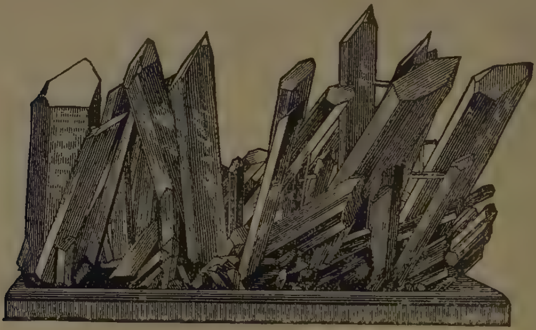

FIG. 64.—Quartz Crystals From *Elements of Crystallography*. By Prof. G. H. Williams (Macmillan and Co.).

Felspars are silicates, *i.e.*, salts formed by the combination of certain basic oxides with silicic acid. They constitute a class of minerals which can be scratched, but not easily, with the point of a knife. They are generally white, or of a pale colour. They belong to two crystalline systems, some to the monoclinic, the others to the triclinic. The felspars belonging to the monoclinic system are referred to as Orthoclastic felspars, from the name of the chief member of the subdivision, orthoclase. Those belonging to the triclinic system are called Plagioclastic felspars.

Orthoclase is a double silicate of aluminium and potassium, and is hence very commonly referred to as *potash felspar*. Its hardness on Moh's scale is 6. Its colour varies between somewhat wide limits, from almost colourless crystals (called sanidine) to grey, brown, or red ones. Under the microscope it is most often present in rectangular sections, which often show decided cleavage cracks, distinctly marked out by the decomposition products occurring along them. Like quartz, orthoclase

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[1] *Physiography for Beginners*, p. 9.

often contains enclosures, but unlike it, is often seen to be zoned. In some rock sections this felspar is observed to be what is called "simply twinned," between crossed Nicols [1] it is found to be divided into two parts, which assume complementary colours as the polariser is rotated.

Plagioclastic Felspars.—These all crystallise in the triclinic system. They are of different chemical composition, as the following table shows :—

Albite, double silicate of sodium and aluminium (soda felspar).
Anorthite, double silicate of calcium and aluminium (lime felspar).
Oligoclase, $\left.\begin{array}{l}\text{intermediate between}\\\text{albite and anorthite}\end{array}\right\}$ albite$_3$ anorthite$_1$ (soda lime felspar)
Labradorite, albite$_1$ anorthite$_3$ (lime soda felspar)

The plagioclastic felspars, like orthoclase, show two well-marked cleavages ; but whereas these cleavage planes are, in the case of orthoclase, inclined at a right angle, in the plagioclastic felspars the angle is always more oblique. It is a difficult matter to tell one plagioclastic felspar from another, especially under the microscope, but orthoclase is distinguished easily enough from the plagioclastic felspars in rock sections ; for, whereas the former only shows the simple twinning above referred to, the latter exhibit a *lamellar twinning*, which causes the crystal to split up into parallel bands of colour between crossed Nicols. The plagioclastic felspars occur in rock sections as rectangular pieces, in which enclosures and a zoned structure are common. Decomposition, too, is usually evident, and is generally recognised along cleavage cracks.

Minerals similar to Felspars which can replace them. Leucite.—This mineral is, like orthoclase, a double silicate of potassium and aluminium, but the proportion in which the constituent elements are present is very different. Its crystalline system is not known with certainty, but it is probably cubic. It is only found in certain lavas, especially those from parts of Italy, and is easily recognised as dull, white, rounded lumps, having a hardness a little below that of the felspars. Under the microscope sections of these little lumps are seen to sometimes be roughly eight-sided, though the angles are more or less rounded off. There is often quite a quantity of foreign matter present, which is symmetrically arranged, either in zones or along radial lines.

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[1] See books on Mineralogy.

Nepheline is composed of the silicate of aluminium, combined with both the silicates of potassium and sodium. It crystallises in the hexagonal system. It differs slightly (as do felspars under like circumstances), when found in deep-seated rocks, from specimens occurring in rocks near the surface. It can be scratched with a knife, and is always more or less decomposed as it is acted upon fairly readily. It is either colourless or only very slightly coloured.

Micas.—The micas are still another class of silicates. They constitute a very important class of minerals, which can be divided into two subdivisions according to the chemical composition of the minerals, viz. : (1) those which contain silicate of aluminium, combined chiefly with some alkaline silicate such as that of potassium, sodium, or lithium, together with smaller amounts of magnesium and iron silicates, and (2) those composed of silicate of aluminium, combined chiefly with silicates of magnesium and iron, the alkaline silicates taking a subsidiary part. All the micas belong to the monoclinic system. We shall only describe the two most important, *muscovite* belonging to the first of the above divisions and *biotite* to the latter.

Muscovite.—This mineral is remarkable for the ease with which its crystals can be divided into plates. It is often soft enough to be scratched by the finger nail. Its colour is always very light, never being darker than quite a light brown. Under the microscope the crystals are seen to be traversed by parallel cleavage marks, and to rarely contain enclosures. The edges of the pieces of muscovite often appear ragged, as a result of their perfect basal cleavage.

Biotite.—This mineral can be regarded as the typical ferro-magnesian mica, just as muscovite is of the alumino-alkaline micas. It is generally of a dark green or black colour when examined in hand specimens; while under the microscope, though most commonly brown or green, is sometimes almost colourless. It is commonly found somewhat altered into greenish decomposition products. The plates into which biotite splits are very much smaller than those of muscovite..

Amphiboles and Pyroxenes.—All these minerals can be regarded as intimate mixtures of silicates of calcium, magnesium and iron, and are often classified as important members of a large class of minerals called the *ferro-magnesian silicates*, to distinguish them from those silicates which contain aluminium and some alkaline base or bases, like many of the minerals we have already described, and which are grouped together as the *alumino-alkaline silicates.* Since these amphiboles and pyroxenes contain iron, they are generally more highly coloured than the felspars and other alumino-alkaline silicates, as well as having a higher specific gravity. We shall have to content ourselves with describing the most typical members of this large group of minerals.

Hornblende, being the most important member of its class, is often called *amphibole.* It is usually found, when in more or less perfect crystals, as elongated prisms belonging to the monoclinic system. Several varieties of the mineral are known, such as *tremolite*, or white hornblende, containing very little iron ; *actinolite*, or green hornblende, which contains more iron than the white variety, but less than common hornblende ; and *asbestos*, a fibrous variety, which is a very bad conductor of heat. In rock sections the crystals generally show six sides and exhibit a very marked cleavage, the angle between the two sets of cracks being 125°. This fact affords a ready means of distinguishing hornblende from augite, which it resembles very closely in several particulars, for the angle between the cleavage lines in sections of augite is invariably 87°.

Augite, sometimes called *pyroxene*, generally occurs in the form of short stout crystals, which are also monoclinic. The colour which the mineral assumes depends, as in the case of hornblende, upon the amount of iron present. Those varieties containing less than the average amount of iron are green, and known as *diopside.* Augite and hornblende are what is called *paramorphic*, *i.e.*, they have the same chemical composition but very different properties. But hornblende is more stable than augite, the latter always shows a tendency to assume the more stable condition of the former.

An intermediate stage in this process of change is found in the mineral *uralite*, which has the general shape of augite, occurring as it does in short stout crystals, but the molecular constitution of hornblende, the angle between the cleavage planes of uralite being 125°. Under the microscope augite often occurs in eight-sided sections, with well-marked cleavage cracks, which, as we have seen, intersect at 87°. Large crystals very frequently show well-developed zones, while both glass and crystalline enclosures are common in most augite. One form of augite, called *diallage*, is of common occurrence in deep-seated rocks, like gabbro. It shows, in addition to the ordinary cleavage cracks, a series of parallel markings, which, acting upon light as a diffraction grating does, gives rise to what is called a *Schiller appearance.*

Rhombic Pyroxenes.—Many ferro-magnesian silicates belonging to the class of minerals we have just described crystallise in the rhombic system, and are of frequent occurrence in rocks. The chief of these are *enstatite*, *bronzite*, and *hypersthene.* The amount of iron present gradually increases from enstatite to hypersthene. Corresponding amphiboles have been recognised, but they are not of great importance.

Olivine is a double silicate of magnesium and iron, which crystallises in the rhombic system. It cannot be scratched by a knife. It is easily altered into *serpentine*, when its appearance is completely different from that of olivine. It sometimes occurs building up rock masses. In rock sections it is generally found as more or less irregular grains, though occasionally it takes the form of an elongated hexagon. Cleavage cracks are only observed when alteration has commenced, and liquid and other enclosures are fairly frequent.

Original Accessory Minerals.—We have already defined (p. 187) what is meant by this heading. We shall only be able here to mention a few of the chief minerals, which, though commonly found in certain rocks, can be absent without very much modifying their general characters.

Magnetite, which is the most ubiquitous of all minerals, is, as the student has learnt,[1] an oxide of iron, which sometimes possesses magnetic properties and is then known as *lodestone.*

Other minerals which fall to be mentioned here, and for a description of which we must refer to works on Mineralogy, are *apatite*, *zircon*, *spinel*, *garnet*, *tourmaline*, *sphene*, *haüyne*, *nosean*, *ilmenite*, and *pyrites.*

Secondary Accessory Minerals.—We shall have to refer to these again when describing the changes which take place in rocks. Many of the essential minerals which we have discussed are also present in certain rocks as secondary accessory minerals, having been formed later than the rock by alterations in it. Others, however, are never essential constituents of rocks, such as *opal*,[1] *chalcedony*,[1] *zeolites*, *leucoxene*, etc.

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[1] *Physiography for Beginners*, p. 137.

CHIEF POINTS OF CHAPTER IX.

A Mineral is a natural substance with a fairly definite chemical composition, which does not vary from part to part of its mass, and which was formed without the help of animals or plants.

A Full Description of a Mineral includes an account of all its characteristic properties, *e.g.* its crystalline shape, general form, surface, colour, lustre, hardness, specific gravity, touch, smell, taste, &c.

Crystallography.—There are six systems into which crystals are divided.

(1) *Cubic crystals* —Three axes of equal length, which all intersect one another at right angles.

(2) *Tetragonal crystals.*—Three axes at right angles; two lateral axes of equal length; the third, the principal, may be either shorter or longer than lateral axes.

(3) *Rhombic crystals.*—Three axes at right angles; all of unequal lengths.

(4) *Hexagonal crystals.*—Four axes; three lateral axes of equal lengths inclined to one another at 60°; the fourth or vertical axis is at right angles to the lateral axes, and may be shorter or longer than these.

(5) *Monoclinic crystals.*—Three axes of unequal lengths. Regarding one as the principal axis, then of the remaining two, one is at right angles to it, the other inclined.

(6) *Triclinic crystals.*—Three axes of unequal lengths which all intersect at angles which are not right angles.

Examination of Minerals before Blowpipe.—Several points are investigated in such an examination, viz. (1) fusibility; (2) flame-coloration; (3) colour imparted to a borax bead; (4) changes on heating in a closed glass tube; (5) changes when heated on charcoal.

Examination of Minerals under the Microscope.—The *petrological microscope* is provided with two Nicol's prisms—(1) the *polariser*, (2) the *analyser*. The *rotating stage* is carefully graduated, and its position can be accurately determined by means of an attached vernier.

Rock-Sections are thin slices of rock, ground smooth on both faces by emery-powder, glued on to a glass slide and covered with a slip of thin glass. They are transparent, except where crystals of magnetite, &c., occur.

Characters observed under the Microscope.—(*a*) External *contour* or *form* of crystals:—They are *idiomorphic* if the edges are well defined, and *allotriomorphic* if the boundaries of the crystals are irregular and determined only by the surrounding constituents. (*b*) *Cleavage-cracks and Enclosures*:—Cleavage-cracks do not always occur in minerals.

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[1] *Physiography for Beginners*, p. 139.

They are often well defined, owing to incipient decomposition occurring along them.

Enclosures may be either gaseous, liquid, glassy or crystalline. Gaseous enclosures are generally either of air or carbon di-oxide. Liquid enclosures may be of water, liquid carbon di-oxide, or saturated solutions of some salt. Glassy enclosures can be recognised by their behaviour under polarised light. Crystal enclosures are most frequently idiomorphic in form.

Classifications of Rock-Forming Minerals. — *Authigenic* minerals were formed either at the same time or after the rock in which they occur. *Allogenic* minerals are older than the rock containing them.

Essential minerals are those "whose presence is implied in the definition of a rock." *Accessory* minerals are such as "whose presence or absence does not sensibly affect the character of a rock."

Original minerals include those which existed before the rock they helped to build up and those formed contemporaneously with it. *Secondary* minerals result from either the alteration or reconstruction of original minerals.

Essential Rock-Forming Minerals.—These include many kinds, chief among which are the following :—

(*a*) *Quartz* and its varieties.

(*b*) The *Felspars*, divided into orthoclastic and plagioclastic felspars. Orthoclase is chief of the first group, and albite and anorthite of the latter.

(*c*) Minerals *similar to Felspars*, and which can replace them—*e.g.*, leucite, nepheline, etc.

(*d*) The *Micas*, *e.g.*, muscovite, biotite and others.

(*e*) *Amphiboles and Pyroxenes*, called also the ferro-magnesian silicates. The chief amphibole is Hornblende, and the characteristic pyroxene is augite; both these minerals crystallise in monoclinic forms. Enstatite, bronzite and hypersthene are rhombic pyroxenes.

(*f*) *Olivine* is a double silicate of magnesium and iron, which crystallises in the rhombic system, and is easily changed into serpentine.

(*g*) *Original Accessory Minerals*, which include magnetite, apatite, tourmaline and others.

(*h*) *Secondary Accessory Minerals*, of which opal, chalcedony and zeolites are typical instances.

QUESTIONS ON CHAPTER IX.

(1) Name the six minerals that occur most commonly as rock constituents, giving the chemical composition of each.

(2) What do you know concerning the chemical composition of quartz, felspar, mica, and hornblende?

(3) State what you know concerning the crystalline form, chemical composition, physical properties, and mode of occurrence of the following minerals :—

(*a*) Magnetite.
(*b*) Calcite.
(*c*) Rock-salt.
(*d*) Graphite.

(4) Into what classes are crystal shapes usually divided? Draw a typical crystal of each system, and name some mineral which is found having the shape you draw.

(5) In describing a mineral, to what points should you attach most importance, and which characters should you consider of little importance?

(6) Of what use is the blowpipe in ascertaining the nature of a mineral? What experiments could be performed with such an instrument which would assist you in this object?

(7) How is a rock prepared for microscopic examination?

(8) What form of microscope is used in the examination of rocks? Enumerate its chief parts, giving a rough sketch of the whole arrangement.

(9) The microscope has revealed the fact that many crystals enclose other substances in their mass. What may the nature of these enclosed materials be, and how did they probably get there?

(10) Give the chief properties of the following minerals:—Quartz, orthoclase, olivine, and augite.

CHAPTER X

THE EARTH'S CRUST

ROCKS AND THEIR CLASSIFICATION

Classification of Rocks according to their Mode of Formation.—The best classification of rocks for our purpose is that depending upon their mode of formation. Following this plan, we obtain three main divisions, viz. : (1) Igneous, (2) Sedimentary, (3) Metamorphic Rocks.

Igneous Rocks.—These include all those rocks which have at some time in their history been in a liquid condition. This fluid state has always been the result of the high temperature to which they have been subjected. Their physical character depends almost entirely upon the *rate* at which they have cooled. In those rocks where the cooling has been comparatively rapid, as is the case, for instance, with the lavas which are poured out from volcanic vents, we obtain what are called *volcanic* rocks, in which crystallisation is by no means perfect, and which consequently have a considerable amount of glassy material entering into their composition. In those rocks, however, where cooling has been very slow, as is the case with those which have cooled deep down in the earth's crust, under the great pressure caused by the weight of the superincumbent layers of the earth's crust, crystallisation is very perfect, and there is little if any glassy material present. Such rocks are called *plutonic*. But, of course, there is no sharply defined line of demarcation between these two kinds of igneous rocks ; they merge the one into the other, and the intermediate rocks are sometimes distinguished by the name of *dyke* rocks.

Sedimentary Rocks.—As the name implies, these rocks have all been, at some time, sediments in water. To mark the fact that their origin is due to the action of water, they are often called *aqueous* rocks. They have been deposited in the order of their specific gravities in the water of some lake or sea, and are consequently arranged in layers or strata, a circumstance which has given rise to the name *stratified* rocks. The materials of which they are formed were obtained either from the disintegration of igneous or metamorphic rocks, or the breaking down of some previously existing sedimentary formation. This process of disintegration is the result of the chemical and mechanical actions of the atmosphere and of running water, and will be referred to at greater length later.

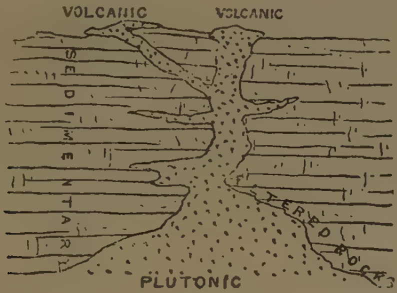

Fig. 65.—Volcanic Rocks cool near the Surface, Plutonic Rocks cool deep down in the Earth's Crust.

Metamorphic Rocks.—All rocks classed under this heading are changed or altered rocks. The changes have been brought about by a variety of causes, such for example as the heat of contact of some intruded mass of molten, igneous rock; or by the great movements of folding or bending, giving rise to enormous lateral pressures, which have from time to time taken place in the earth's crust. As we shall see, there is a great diversity in character among the rocks of this class.

These three great classes of rocks are mutually dependent the one upon another. Their interdependence becomes at once apparent when it is remembered that, starting with igneous rocks, we obtain by their disintegration the materials necessary for the formation of the sedimentary rocks, and that these stratified rocks may, under the influence of the metamorphic changes which we have briefly mentioned, give rise to rocks styled metamorphic, which in some cases can only be distinguished from igneous rocks with the greatest difficulty.

Classification of Igneous Rocks.—Igneous rocks may be classified in a variety of ways. First, there is the division, depending upon the circumstances under which they have cooled from a liquid condition, into the classes known as volcanic, dyke, and plutonic rocks; or, igneous rocks may be arranged according to their *chemical composition*, the basis of such classification being the percentage of silica present in the rock. This division results in the following four classes, viz. :—

(i.) *Acid igneous rocks*, containing 66 to 80 per cent. of silica.

(ii.) *Intermediate igneous rocks*, containing 55 to 66 per cent. of silica, and subdivided into *sub-acid* intermediate rocks, with 60 to 66 per cent. ; and *sub-basic* intermediate rocks, containing 55 to 60 per cent. of silica.

(iii.) *Basic igneous rocks*, containing 45 to 55 per cent. of silica, and so called because the basic oxides present are more abundant than the acid-forming oxide silica.

(iv.) *Ultra-basic igneous rocks*, containing 35 to 45 per cent. only of silica.

A third classification is based upon the *minerals which the rock contains*. The following, for instance, is that of Mr. J. J. Harris Teall.[1]

A. Rocks composed of the ferro-magnesian minerals : olivine, enstatite, augite, hornblende, biotite. Felspar absent ; or, if present, occurring only as an accessory constituent.

B. Rocks in which plagioclase is the dominating felspathic constituent. Nepheline and leucite absent. Orthoclase is frequently present.

C. Rocks in which orthoclase is abundant. Plagioclase is usually present. Nepheline and leucite absent.

D. Rocks containing nepheline *or* leucite ; sometimes nepheline *and* leucite.

E. Rocks not included in any of the preceding classes.

F. Vitreous rocks.

G. Fragmental volcanic rocks.

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[1] See *British Petrography*, J. J. Harris Teall, F.R.S.

Acid Igneous Rocks.—It will be most convenient for us to adopt the chemical classification of the igneous rocks; and the reader must understand, that to be certain of the class to which any given rock belongs in such a system, we must make a quantitative chemical analysis of it, and so ascertain the percentage of silica it contains. Such an analysis is of course impossible in the field; and if it is desirable to classify it on the spot for the purpose of a geological survey, it is often more convenient to adopt the mineralogical classification, since an examination with a pocket lens is generally sufficient, at all events with coarsely crystalline rocks, to determine the minerals of which it is built up. In the case of other igneous rocks an examination of a slice of it under the microscope, together with a chemical analysis, are the only satisfactory means of exactly locating its position in any system of classification. The acid igneous rocks include, like every one of the other classes, a plutonic, dyke, and volcanic representative. The plutonic acid rock is **granite**, which, having cooled very slowly, is perfectly crystalline, and is hence said to be *holocrystalline*. A typical granite contains three essential minerals, viz., quartz, orthoclase, and muscovite. But the muscovite may be wholly or partly replaced by several other minerals, *e.g.*, hornblende, less commonly biotite, and in few rare instances, augite. There is often a certain amount of plagioclase present. Accessory minerals are always found, and these are most often one or other of such minerals as apatite, sphene, zircon and garnet. Sometimes one or other of the essential minerals may be absent, when the rock ceases to be a granite. If the felspar is absent the aggregate of quartz and muscovite is known as *greisen*. If the muscovite is missing, the rock composed of the remaining orthoclase and

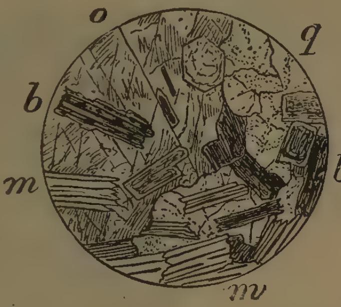


FIG. 66.—Microscopic Section of Granite; *o*, is orthoclase; *q*, is quartz; *m*, is muscovite; *b*, is biotite. From *Aids in Practical Geology*, by Prof. G. A. J. Cole. (Charles Griffin and Co., Ltd.)

quartz is called *aplite.* Slices of granite under the microscope vary considerably in detail, but an idea of their appearance can be obtained from Fig. 66, which is a section of a specimen from near Dublin. The quartz is clear like glass, and its allotriomorphic grains fill up the spaces between the other crystals. The orthoclase has a clearly marked outline, though, owing to the decomposition it has undergone, it is cloudy. The parallel cleavage cracks along the pieces of muscovite show where the crystal, from which the section was obtained, would split into the plates to which we have already called attention (p. 190). In a great many granites the crystals of which the rock is made up are not large enough to be recognised by the unaided eye; they can only be distinguished under the microscope. These varieties are said to possess a *micro-granitic structure*, in contradistinction to the coarsely crystalline one of ordinary granites.

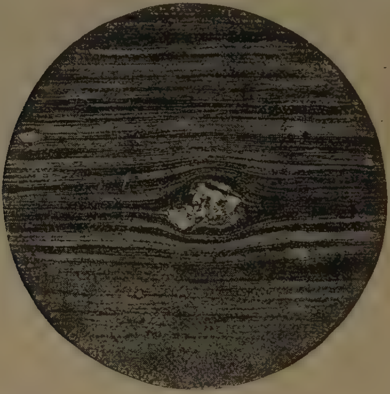
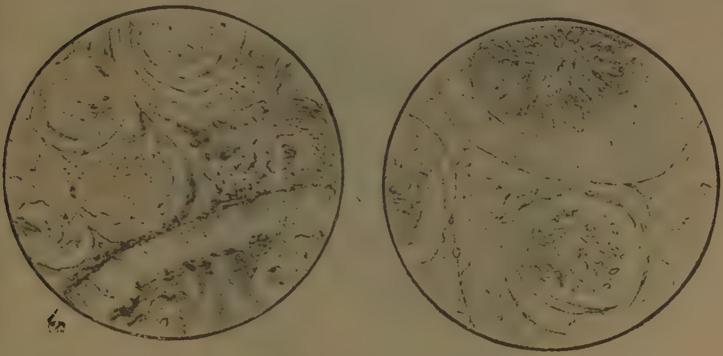


FIG. 67.—Micro-structure of Porphyritic Obsidian. From Merrill's *Rocks, Rock-weathering, and Soils.* (Macmillan and Co.)

Two varieties of volcanic acid rocks may be distinguished, first, those in which the cooling was very rapid indeed and the consequent rock entirely glassy; secondly, those where the cooling was less rapid, and the rock is what is known as *hemicrystalline*, *i.e.*, composed partly of crystals, partly of glass, and partly of those early stages in the growth of crystals called *crystallites.* The perfectly glassy volcanic acid rock is called **obsidian.** In appearance it is not distinguishable, except where weathering has commenced, from bottle-glass. Like bottle-glass it sometimes undergoes a very slow process of crystallisation, called devitrification, which results in the formation of crystallites, spherulites, perlitic cracks, etc., and very gradually completely alters the nature of the rock (Figs. 68 and 69). Obsidian is found in Lipari, the Yellowstone Park and other places. The hemicrystalline volcanic acid rock is called **rhyolite.** The chemical composition is, as would be gathered from its position among the acid rocks, roughly the same as that of granite and obsidian. The minerals of granite are sometimes distinguishably dotted in a compact ground-mass, or as it is generally expressed, *porphyritically* arranged. The rock is often made up of alternating bands, of different colour and composition. The characteristic fluidal structure (Fig. 67) is, too, very common, affording indisputable evidence that the rock must have flowed during the process of cooling.



FIGS. 68 and 69.—Microscopic Sections of Devitrified Glassy Lavas, showing Spherulites, etc.

FIG. 68.—Perlitic Cracks and Large Spherulite in Devitrified Obsidian, from Boulay Bay, Jersey.

FIG. 69.—Spherulites surrounded by Perlitic Cracks in Specimen from Yellowstone.

(Rutley, Q.J.G.S., Vol. L., Plate I.)

Intermediate Igneous Rocks. *Sub-acid division.*—The holocrystalline plutonic representative, **syenite**, contains as essential constituents the minerals orthoclase and hornblende. The place of the hornblende may be taken by augite or mica, when we get *augite-syenite* and *mica-syenite* respectively. In most syenites there is usually some plagioclase and quartz. Zircon and sphene are common accessory minerals. Since, as we have said, syenite contains some quartz it is very evident that these rocks graduate into the granites. Under the microscope, sections of syenite show the same general structure characteristic of granite, and which is sufficiently typical to have given rise to the expression *granitic structure.* The volcanic equivalent of the syenites are known as **trachytes** (Fig. 70). The same relation exists between these rocks and the syenites as holds good between the rhyolites and the granites. The trachytes, which get their name from the characteristic roughness of such lavas, contain the same essential minerals as, and a chemical composition similar to, the syenites. The proportion of glass per cent. is less in the trachytes than in the rhyolites, and consequently fluidal structure is less common. The orthoclase is generally the clear variety known as sanidine. There is, also, a highly glassy volcanic variety

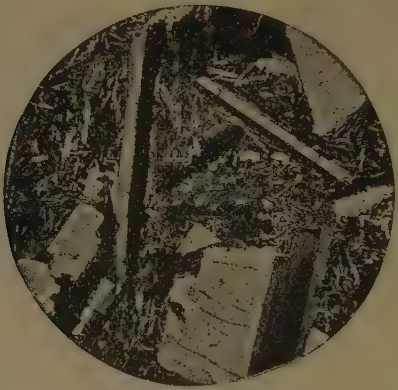


FIG. 70.—Micro-structure of Trachyte. From Merrill's *Rocks, Rock-weathering, and Soils.* (Macmillan and Co.)

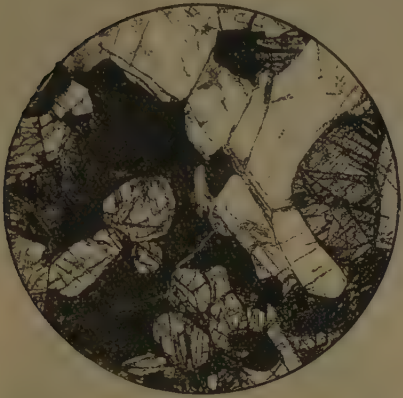


FIG. 71.—Microscopic Section of Gabbro. × 25.
[Geikie and Teall, Q.J.G.S., Vol. L., Plate 28.]
Minerals present are plagicclase, augite, and magnet

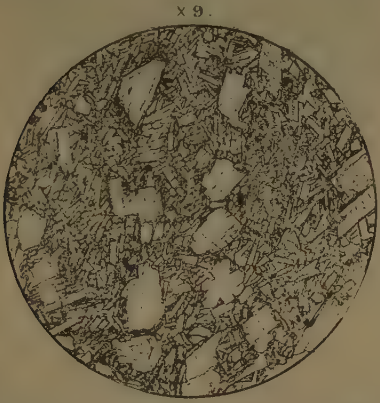


FIG. 72.—Microscopic Section of Augite-andesite from Hill of Allen, Kildare.
[Reynolds and Gardiner, Q.J.G.S., Vol. LII., Plate 28.]
Numerous small, square-edged, felspars, also larger porphyritic felspars are well shown.

known as *trachyte glass*, which shows a less decided tendency to devitrification than obsidian.

Sub-basic division.—The plutonic form of this division of igneous rocks is called **diorite**. It is essentially a holocrystalline aggregate of plagioclastic felspar (usually oligoclase or labradorite) and hornblende ; but the place of the hornblende may be taken by augite or mica as in the case of the syenites. There is little or no quartz. Magnetite and ilmenite are generally found as accessory minerals, and epidote is a very common secondary product. This rock is still sometimes called *greenstone*, which is, however, a loose field term including several kinds of igneous rocks. The volcanic equivalents are here **andesites** (Fig. 72) and *andesite glass*, related to one another after the same fashion as trachyte and trachyte glass. The andesites, which take their name from the Andes Mountains, where they occur in great quantities, are perhaps the most abundantly found of all the igneous rocks. The mineral constituents are the same as in the diorites, and they sometimes occur porphyritically scattered in the hemicrystalline ground mass.

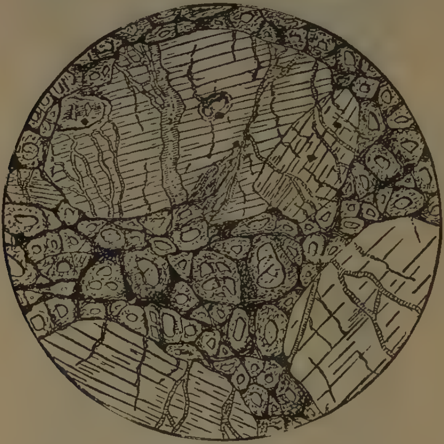


FIG. 73.—Micro-structure of Porphyritic Lherzolite, partly altered into Serpentine. The Section illustrates porphyritic structure produced by the development of large pyroxene crystals in a fine granular ground-mass of olivine. From Merrill's *Rocks, Rock-weathering, and Soils.* (Macmillan and Co.)

Basic Igneous Rocks.—**Gabbro**, the holocrystalline plutonic representative of this division of the igneous rocks, contains as essential constituents the following minerals, viz., plagioclastic felspar (usually labradorite or anorthite) (Fig. 71), augite (generally in the form of diallage), and olivine. If olivine is absent it is more common to class the rock with the diorites, though some authorities call an aggregate of plagioclase and diallage a gabbro. Hornblende and mica are not commonly present, though magnetite and ilmenite are always found. The examination of sections under the microscope will always decide whether olivine occurs, though it is sometimes difficult to recognise its presence in hand specimens. The olivine is to be distinguished in sections by its rounded grains, which show, as a rule, alteration into serpentine (Fig. 73), especially along the cleavage planes. Where no alteration has taken place, the olivine grains are quite clear. Just as gabbros, in which there is little or no olivine, are often placed among the diorites, so, those specimens of **basalt**, (Fig. 74) the volcanic equivalent of these rocks, which do not contain olivine, are placed with the andesites, though to mark this distinction the basalts containing olivine are always spoken

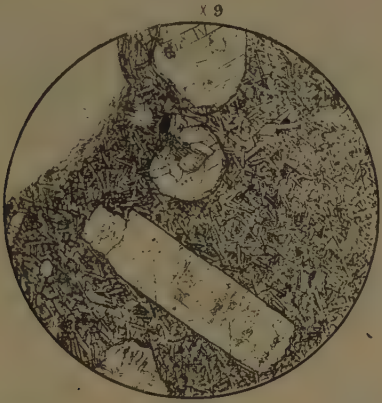


Fig. 74.—Microscopic Section of Porphyritic Basalt from Hill of Allen, Kildare. [Reynolds and Gardiner, Q.J.G.S., Vol. LII., Plate 28.]
The rounded crystals in the upper part of the section are of augite. The large crystal in the middle is of labradorite.

of as *olivine basalts* (Fig. 75). The essential minerals are, as usual, the same as the holocrystalline variety, in this case gabbro. The ground mass contains a smaller proportion of glass than that of the other volcanic rocks described. In hand specimens some species of basalt are very similar in appearance to dark-coloured limestones, but can be easily distinguished therefrom by the superior hardness of the basalts, or by the ready action of dilute hydrochloric acid on the limestones. The highly glassy volcanic member of the basic group of igneous rocks is called *tachylite* or *basalt-glass*. Other rocks belonging to this group are the *dolerites*, which are intermediate in position between the gabbros and basalts, and which when altered are called *diabases*.

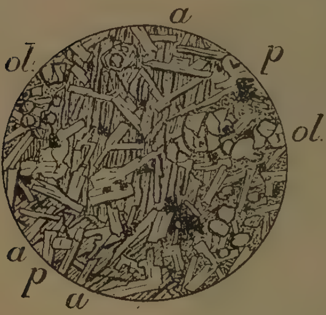


FIG. 75.—Section of Olivine-basalt from Isle of Mull, as seen under microscope, × 25. *a*, Augite; *p*, Plagioclastic Felspar; *ol*, Olivine. Drawn by Prof. G. A. J. Cole. (Reproduced from *Knowledge*.)

Ultra-basic Igneous Rocks.—These rocks are sometimes known as the **peridotites.** They are very rich in olivine, which is sometimes present to the extent of 50 per cent., as in certain *picrites*. The essential minerals vary considerably. Usually some pyroxene, amphibole, or mica is present with olivine, and varying amounts of magnetite, ilmenite, chromite, etc. The large percentage of olivine present, which undergoes ready decomposition, causes the rocks to quickly become changed into some variety of the group of *serpentines* (Fig. 76). Others of the best known ultra-basic rocks are *lherzolite* (Fig. 73) and *dunite*.

The student must remember that the above account is of the most general kind. Only the most important igneous rocks are mentioned, while one or two only of the leading characters are given. For a full account of this interesting branch of the subject, reference should be made to works on Petrology.[1]

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[1] See, e.g., *The Student's Lyell*, by Prof. Judd; or *Aids in Practical Geology*, Prof. Cole.

Disintegration of Igneous Rocks.—The materials which build up the sedimentary rocks *can* all be derived from the breaking down, or disintegration, of igneous rocks; though we must not go so far as to say they have been so obtained. This decomposition is brought about by atmospheric agencies. The changes which take place, though not identical with, are comparable to, those happening in the case of granite, which we shall now describe.

Typical granite contains, as we have seen, quartz, orthoclase, and muscovite. The atmosphere is a mixture of oxygen and nitrogen, with much smaller amounts of water vapour and carbon dioxide. The effect of the atmosphere, or *weathering* as it is called, upon quartz is insignificant; but upon felspars it produces profound changes. Thus, in the case of orthoclase, which is a double silicate of aluminium and potassium, the first result of the air's action is to separate these silicates. The aluminium silicate thus set free undergoes no change other than that of becoming hydrated by combining with water. The potassium silicate is however acted upon by carbon dioxide, with the result that a double decomposition gives rise to

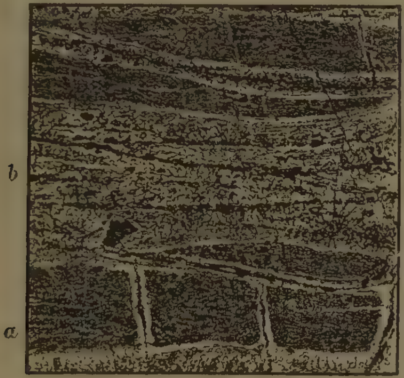


FIG. 76. Intrusive Serpentine from the Lizard District (× 8). *a* is a band of Orange-coloured Serpentine, *b* one of lighter colour.
(Bonney, Q.J.G.S., Vol. LII., Plate I.)

potassium carbonate and silica. This silica is soluble in water containing potassium carbonate in solution. In the case of the felspars, albite and anorthite, the only difference will be that the former gives rise to sodium carbonate, and the latter to calcium carbonate, in the place of the potassium carbonate resulting from orthoclase. It is these changes, known as *kaolinisation*, which causes the cloudiness in felspar crystals when seen in sections of igneous rocks, where the decomposition is in its earliest stages.

The changes which the muscovite experiences are the same in kind, though much smaller in amount, than those happening in the felspars.

After these changes have gone on for some time the solid mass of igneous rock completely changes its appearance. The crystals of felspar become decomposed into soluble and insoluble constituents; the former are dissolved by the rain, while the latter are carried away in suspension. There is no longer anything to bind the constituents of the rock together, and the insoluble quartz and little-acted-upon muscovite similarly become washed away. These materials are deposited again under suitable conditions, and give rise first to sediments, which, becoming hardened, produce the sedimentary rocks.

Sedimentary or Aqueous Rocks.—These rocks are best classified according to the materials out of which they are formed as follows :—

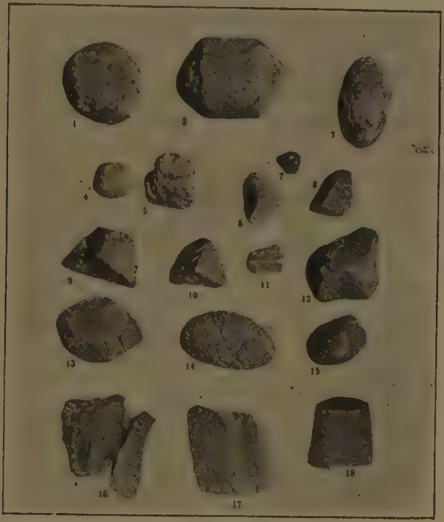
(i.) Siliceous Aqueous Rocks, mainly derived from the insoluble quartz which results from the decomposition of igneous rocks, and which becomes separated from the other waste products by the action of running water.

(ii.) Argillaceous Aqueous Rocks, mainly derived from the insoluble aluminium silicate, resulting from the decomposition of the felspars and other silicates contained in igneous rocks.

(iii.) Rocks formed from the soluble products of the decomposition of igneous rocks, and including those formed by (*a*) chemical means, (*b*) the aid of animals and plants.

Siliceous Aqueous Rocks. Sands.—These consist of loose, incoherent grains of quartz and other minerals, which must be small in size, though no hard and fast limit can be drawn, as the sands gradually shade into *gravels* and *shingles*. Several types of sand are known. Mr. Sorby has divided them into five classes, according to the nature of their constituent grains.[1]

The minerals which are most commonly found in addition to quartz are zircon, rutile, tourmaline; while many others, such as felspars, micas, magnetite, etc., have also been recognised.



⅖ Natural Size.

FIG. 77.—Wind-, Heat-, and Water-worn Stones from the Desert near Biskra (except Nos. 7 and 8).

1—6 show effects of wind action; 2 is a good example of the effect of rolling and wind-polishing.

7, 8. Glacier marked stones from Berne.

11, 12. Stones polished by blown sand, and showing rain-effects.

13, 14. Examples of cracks produced upon limestone by sudden changes of temperature.

15. Limestone with pitted surface produced by wind and fine-blown sand.

16, 17, 18. Sand-polished pebbles.

(From *Mittheilungen der naturforschenden Gesellschaft in Bern*, 1895).

Sand grains appear to become more rounded when they have been subjected for a long time to the action of the wind, than if exposed to the drifting action of running water alone (Fig. 77).

Sandstones can be regarded as sands compacted together by the action either of pressure or of infiltration (Fig. 78). In the latter case some solution, say one of lime, has percolated into the mass of the sand, and evaporated, and the dissolved substance left behind binds the constituent grains together. Such a sandstone would be called *calcareous.* In the *red sandstones* the cement is one of the oxides of iron. Similarly *argillaceous* and *siliceous* sandstones are known. *Freestone* and *flagstone* are used for building and paving respectively. *Micaceous sandstone* contains flakes of mica along the planes of bedding.

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[1] *Quarterly Journal of the Geological Society*, 1880, p. 58.

Gravels and **Shingles.**—These materials, like the sands, are unconsolidated aggregates of water-worn pieces of a most diverse character. Shingles are generally regarded as made up of large rounded pebbles, which may reach the size of a football; while gravels may contain lumps of all shapes, some of which at least are angular, though the size is usually supposed to vary from that of a pea to that of a billiard ball. Consolidated gravels, where most of the fragments are rounded, are known as *conglomerates* or *pudding-stones.* The cement binding the larger pebbles together is made up of finer grains. Where the

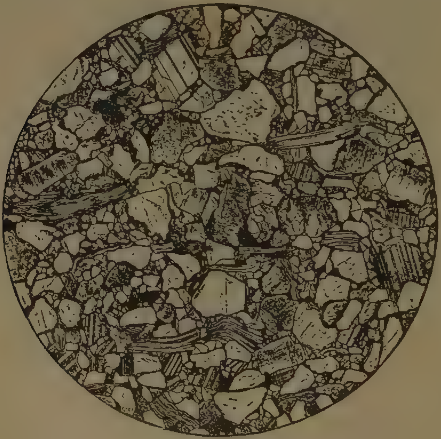

FIG. 78.—Micro-structure of Sandstone.
From *A Treatise on Rocks, Rock-Weathering, and Soils.* By G. P. Merrill. (Macmillan and Co.)

pebbles of a conglomerate are replaced by angular fragments the resulting rock is called a *breccia* or an *agglomerate*. Other siliceous rocks, or as they are sometimes called *arenaceous* rocks, are known, but their consideration belongs rather to Geology than to our subject.

Argillaceous Aqueous Rocks.—Pure hydrated aluminium silicate is known as *kaolin*, or *Cornish china-clay*. It is not of common occurrence, being chiefly found where granite has undergone a great deal of disintegration, as in the Luxulyan Valley of Cornwall. Most often the aluminium silicate is found mixed with such impurities as lime, sand, oxide of iron, etc. All such impure forms of aluminium silicate are known as *clays*. Their colour varies with the percentage of iron present. When there is an almost complete absence of alkaline silicates the clay is known as *fire-clay*, because of its infusibility when subjected to great heat. *Brick-clay* is any clay suitable for the manufacture of bricks; it is usually remarkable for its large percentage of iron compounds. The unconsolidated impalpable sediments from which clays are derived are known as *muds* and *silts*. *Mudstone* and *shales* are both hardened mud; they differ from one another in the power possessed only by the latter of being divisible into thin laminæ. Some clays possess so large a proportion of carbonaceous material as to be useful as fuel, such varieties being designated *carbonaceous shales*.

Rocks formed from the Soluble Products of the Decomposition of Igneous Rocks. 1. By Chemical Means.—The chief soluble products of the decomposition of igneous rocks are, from this point of view, silica and calcium carbonate. Both these compounds are insoluble in pure water. The first owes its solution to the presence of alkaline carbonates in the water, the latter to the dissolved carbon dioxide.

Rocks formed from Dissolved Calcium Carbonate by Chemical Means, *i.e.*, by the loss of the dissolved carbon dioxide and subsequent deposition of the dissolved carbonate, are *Travertine* or *Calcareous Tufa; Stalactites* and *Stalagmites; Pisolitic* and *Oolitic Limestones.*

We have already described[1] how travertine, stalactites, and stalagmites are formed, and shall in this place briefly refer to the **pisolitic** and **oolitic limestones**. They differ from one another only in the size of the grains of which they are composed; those of the pisolites may be as large as peas, while those of the oolites are very small indeed, the name itself being derived from the likeness of the structure of the rock to that of the roe of a fish. An examination of sections of oolitic limestones under the microscope has shown that the spherical grains of which it is built up are composed of concentric layers, arranged round a tiny central piece of sand or other material (Fig. 79). The process of their formation can at the present day be watched in the mineral springs of Carlsbad. They have however been recognised in limestones of the most diverse geological ages, and there is little doubt that they can also be formed in seas or lakes, the water of which is more or less saturated with calcium carbonate, and where there is current enough to keep the nucleus of sand moving, so that the deposition of chalk may take place more or less regularly around it.

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[1] *Physiography for Beginners*, p. 300.

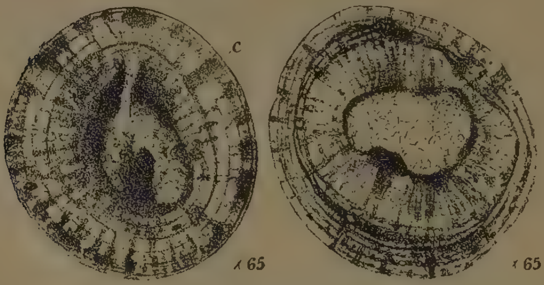

FIG. 79.—Oolitic Granules from the Forest Marble near Cirencester. (Wethered, Q.J.G.S., Vol. LI., Plate 7.)

Other chemically formed rocks composed of materials, which, though ultimately derived from igneous rocks, are only obtained in an indirect manner, are *rock-salt*, *gypsum*, *dolomite*, and the *ironstones*. These have already been described.[1]

Rocks formed from Dissolved Silica.—Siliceous sinter or, as it is sometimes called, *geyserite*, is deposited round the orifices of geysers and hot-springs. It contains about 90 per cent. of silica, and varying amounts of other substances, such as oxides of iron, alumina, lime, etc. It is often quite white, though sometimes it has a slight yellow colour.

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[1] *Physiography for Beginners*, p. 240.

Rocks formed by the Aid of Animals and Plants.—These are the organically formed rocks, of which the student has already learnt.[1] Under this heading fall (1) those composed of calcium carbonate, and (2) those composed of silica. We have further to distinguish between those which are the result of the action of animals and those which were made by plants. The *coccoliths* and *coccospheres* (Fig. 80), which are invariably found in the calcareous oozes from the floor of the oceans, as well as in the chalk formations of different parts of the world, owe their existence to the secreting power of certain minute *algæ*, or seaweeds.

Quite a number of rocks are composed of the remains of animals which possess the power of extracting calcium carbonate from the waters in which they live. These need only be mentioned. The chief are *Globigerina ooze*, *chalk*, *coral*, *coral-rock*, and *limestones*. The student should carefully reread the part of our elementary book dealing with these rocks.

Of the organic rocks composed of silica which were formed by plants, the chief are the *diatomaceous earths* and *tripoli powder*. The small algæ, which extract silica from the water in which they live, are called *diatoms*. They live in both salt and fresh water, and are as active to-day as they were in past ages, when such extensive deposits as that of Richmond, in Virginia, which is 40 feet thick, were formed. The silica-secreting animals belong to the very lowest forms of animal life, and are called *Radiolaria*. Their remains build up the *radiolarian earths*. The siliceous sponges also secrete silica to form the *spicules* which are commonly found associated with the remains of radiolaria.

Organic Rocks formed of the Remains of Land Plants.—It will be unnecessary to do more than mention these rocks in this place, as the student has already become familiar with them.[2] They include *peat*, *lignite*, *coal*, *anthracite*, and *graphite*. There is a gradual gradation in structure and chemical composition as we pass from peat to graphite. Peat approaches wood in composition, containing as it does about 60 per cent.

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[1] *Physiography for Beginners*, pp. 302–308.

[2] *Ibid.*, pp. 306–308.

of carbon, 6 per cent. of hydrogen, and 34 per cent. of oxygen and nitrogen. But as the process of mineralisation is carried further, there is a continuous diminution in the amount of hydrogen, oxygen, and nitrogen, and a consequent greater and greater percentage of carbon as we approach anthracite ; while, in the case of graphite, this elimination of the gaseous elements we have named is completed, and a rock obtained which contains approximately 100 per cent of carbon.

Metamorphic Rocks.—We have seen that granite and other igneous rocks are slowly altered by the weathering action of atmospheric agencies, causing them to eventually become completely disintegrated or broken up. Many other changes of a somewhat similar kind are continually going on, both in sedimentary and igneous rocks. Thus, for example, magnetite, and other oxides of iron, combine with the elements of water becoming *hydrated* ; and olivine is similarly slowly changed into serpentine. All such changes brought about by the action of water, either that charged with carbon dioxide which is obtained from above, or that forced up from lower heated regions, are classified together under the general heading of *alterations*. Sometimes the term *hydro-metamorphism* is used to designate these changes, which generally leave the original structure of the rock more or less unaltered.

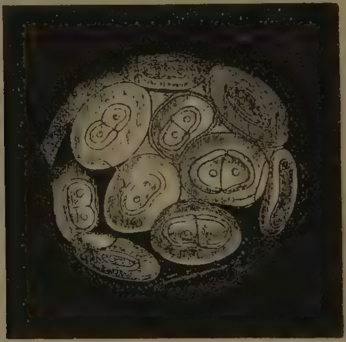

FIG. 80.—A Coccosphere ; 1,000 times its natural size.
(*Natural Science*, Vol. VII., No. 41, p. 25.)

Those changes, on the other hand, which cause a rock to completely lose its original texture and to become crystalline, are classed as *metamorphic changes*, and are said to be due to *metamorphism*. Such metamorphism is the result, as a rule, of two prime operating causes. First, that due to the heat of contact with great masses of intruded molten rock, which is, by the expansive force of steam, or some other cause, forced from below into crevices and fissures, or between the beds of the superincumbent stratified rocks. This is called *contact-metamorphism*.

Secondly, that brought about by the action of enormous pressures from the sides, which is generally the outcome of slow movements of the earth's crust, or *crust-creep*, and known as *dynamo-* or *regional-metamorphism*.

Rocks changed by Contact - Metamorphism.—1. *Those derived from clays and shales.* When clays and shales are subjected to the heat of contact of intruded masses such as we have mentioned, it becomes first changed into a *clay-slate*, a rock of an indefinite character, which generally shows a certain degree of cleavage, and also in microscopic examination some amount of change into crystalline materials. When the metamorphism is carried further and recrystallisation has become more pronounced, secondary minerals, such as mica, chiastolite, etc., make their appearance and we obtain rocks which are named from the predominating secondary mineral they contain. Thus, a clay-slate with a marked development of mica-flakes along its cleavage planes is known as a *phyllite*. Where chiastolite crystals are common we get a *chiastolite-slate*, and so on. When the baking is very pronounced we obtain flinty-looking rocks, such as *porcellanite* and *lydian-stone*. As would be expected the changes are most pronounced in the immediate neighbourhood of the intruded mass; as this is left the porcellanites give place to slates where the changes are less and less marked.

2. *Those derived from sands and other siliceous rocks.*—Where metamorphism has been fairly complete, we obtain rocks known as *quartzites* (Fig. 81). Though hand-specimens and sections under the microscope both reveal its origin from quartz grains, yet these minute fragments are firmly cemented together, and the rock cannot be pounded up like a sandstone. It breaks

with the conchoidal fracture characteristic of glassy masses. Quartzite is sometimes coloured in a similar way to sandstones, the extent of the colouring depending upon the amount of iron present in the sand from which it was derived. There can be no doubt that quartzite was originally a sandstone, both from its granular appearance under the microscope and from the fact of its retaining the original characters it possessed as a sedimentary rock. When there is a sufficient amount of mica present in the rock, developed along distinct folia and causing it to possess a certain degree of schistosity, it is known as a *quartz-schist*. We must remark that some authorities place quartzite among those rocks which are the result of regional metamorphism.

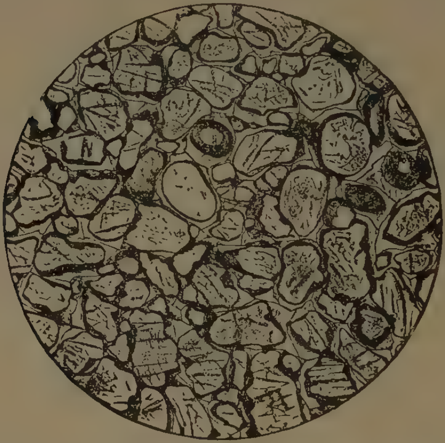

FIG. 81.—Micro-structure of Quartzites, showing secondary deposit of Silica about the original Quartz Grains. From Merrill's *Rocks, Rock-Weathering, and Soils.* (Macmillan and Co.)

3. *Those derived from calcareous rocks.*—The calcium carbonate from which these rocks are derived may be either of organic, or what we have called chemical origin. The altered calcareous rocks are either *marble* or *crystalline limestones.* Though typical marble is white, it may, as the result of impurities of one kind or another, be of almost any colour. These

rocks may also be formed by the agency of dynamo-metamorphism. Other minerals are often found present, *e.g.* mica, garnet, actinolite, etc.

Rocks resulting from Dynamo-Metamorphism.—While all the changed rocks which have up to the present been described retain their original structural characters, those which are the outcome of this second order of metamorphism, which takes place on a far larger scale, undergo in the process a complete change of character. A new rock with altogether different features is the result. The effect of regional-metamorphism upon shales, for instance, is to change it from a rock which easily divides into laminæ along the planes of bedding, that is from being a *laminated rock*, into one known as a slate, which exhibits the phenomenon of *cleavage.* The rock no longer splits along the original planes, but along a new set which are usually vertical or inclined at angles approaching a right angle (Fig. 82). Moreover, under the microscope the component particles are seen to be re-arranged in a manner which is most easily understood from a comparison of Figs. 83 and 84. Such cleavage is most perfectly developed in fine-grained rocks, such as shales, where the constituent particles are very small and easily re-arranged with their long axes parallel. Still a roughly-cleaved structure is sometimes assumed even by sandstones and other coarse-grained rocks. Cleavage has been artificially produced, by the action of great pressure exerted from the sides, both by Sorby and Tyndall; by the former in a mass of pipe-clay in which flakes of oxide of iron were disseminated, and by the latter in blocks of beeswax and paraffin. The deformation

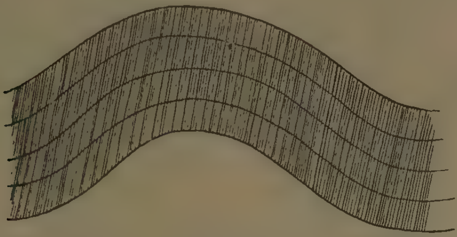

FIG. 82.—Diagram showing the Planes of Cleavage at right angles to the Stratification Planes. From Prof. W. B. Scott's *Introduction to Geology.* (Macmillan and Co.)

which results from the influence of these great lateral pressures is often very considerable, as is seen, for instance, from the alteration in shape of the little circular green patches which occur in some slates. These patches are caused by the colouring of the original clay or shale by little crystals of iron pyrites found in the rock. After cleavage has been developed, the circular patch is seen to have been drawn out in a direction at right angles to the line of action of the pressure causing cleavage, giving rise to an elliptical form. Similarly, fossils are often found distorted, also being elongated in the direction parallel to the planes of cleavage. An examination of sections of cleaved rocks under the microscope shows that in some cases such cleavage is due to the development of new minerals, such as mica, along the planes where cleavage occurs.

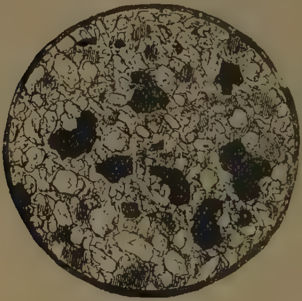

FIG. 83.—Microscopic section of Shale. (Forbes.)

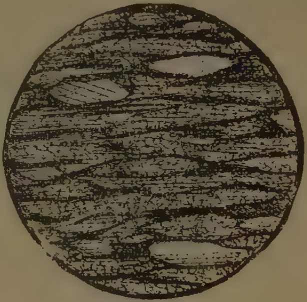

FIG. 84.—Microscopic section of a Slate, showing minute structure of a Cleaved Rock. (Forbes.)

While cleavage is chiefly a mechanical change there is another more or less parallel structure developed in rocks by dynamo-metamorphism which must be regarded as essentially a chemical change. This is *foliation*, which differs from both lamination and cleavage. Geikie defines foliation as "a crystalline segregation of the mineral matter of a rock in certain dominant planes, which may be those of original stratification, of joints, of cleavage, of shearing, or of fracture."[1]

It would take us too far to discuss the various theories which have been proposed to explain foliation. We shall be able only to describe a few of the rocks in which this structure occurs. These rocks include amongst others the *schists* and *gneiss*. In all these foliation is very pronounced, the folia cannot be easily separated, are not strictly parallel to one another, but form lenticular-shaped layers, *i.e.* which are thickest in the middle and drawn out towards the ends. Not only has there been a segregation of minerals along the planes of foliation, but the rocks have been very much crumpled and contorted. Some of the commonest schists are :—

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[1] *Text-book of Geology*, 3rd edition, p. 324.

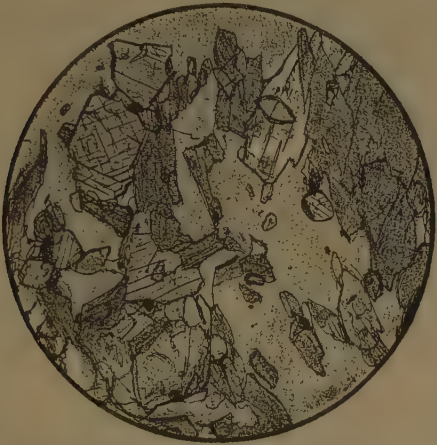

FIG. 85.—Microscopic section of Hornblende-schist, Lizard ; showing Augite and Hornblende in a Felspathic Base (× 60).
(McMahon, Q.J G.S., Vol. L., p. 357.)

Hornblende-schist, a schistose mass (Fig. 85) of common hornblende, interleaved with felspar, quartz, or mica.

Mica-schist, a similar rock, made up of folia of mica and quartz, the relative proportion of these minerals varying much in different specimens.

Argillaceous-schist, or clay-slate, which is of a variable composition. Though sometimes formed by contact-metamorphism as already mentioned (p. 215), it is more generally the result of regional-metamorphism on a variety of argillaceous deposits. Many rocks, such as *whetstone*, *honestone*, etc., fall under this heading.

Gneiss is composed of the same minerals as granite, which are arranged in folia very much thicker and coarser than those making up rocks like the mica-schists. Many varieties are known, depending upon the accessory minerals present and the nature of the constituent folia. The folia are often recognisable even in small specimens. There can be no doubt that many gneisses have been formed by the foliation of such plutonic rocks as granite.

CHIEF POINTS OF CHAPTER X.

General Classification of Rocks.

Rocks.
- *igneous*, have once been in liquid condition.
- *stratified*, have once been sediments in water.
- *metamorphic*, have been greatly changed from the original igneous or stratified condition.

Igneous Rocks.

	ACID. Silica : 60—80 per cent.	INTERMEDIATE. *Sub-acid.* Silica : 60—66 per cent.	 *Sub-basic.* 55—60 per cent.	BASIC. Silica : 45—55 per cent.
Typical Rocks contain	(i) *Quartz* (ii) *Orthoclase* (iii) *Mica* (*generally Muscovite*)	(i) *Orthoclase* (ii) *Hornblende*	(i) *Plagioclastic Felspar* (ii) *Hornblende*	(i) *Plagioclastic Felspar* (ii) *Augite* (iii) *Magnetite* (*often Olivine*)
VOLCANIC and GLASSY	Pumice Obsidian	Trachytic Pumice	Andesitic Pumice	Tachylite
VOLCANIC and HEMICRYSTALLINE	Rhyolite	Trachyte	Andesite	Basalt
PLUTONIC and consequently HOLOCRYSTALLINE	Granite	Syenite	Diorite.	Gabbro

Ultra-basic Rocks also called *Peridotites*. They contain less than 45 per cent. of silica, and are very rich in olivine. Picrite, lherzolite, and dunite are good examples.

Disintegration of Igneous Rocks.—Granite may be taken as an example.

GRANITE

- Quartz
  - No change [*Insoluble*, grains washed away].
- Orthoclase
  - Decomposed into Aluminium Silicate and Potassium Silicate.
    - Aluminium Silicate. No further change [*Insoluble*].
    - Potassium Silicate, acted upon by Carbon Dioxide, giving rise to
      - Potassium Carbonate [*Soluble*].
      - Silica [*Soluble*].
- Muscovite
  - Changes very small, same in kind as Orthoclase.

Note.—In case of other felspars, sodium carbonate or calcium carbonate is obtained instead of potassium carbonate.

Igneous Rocks by their Disintegration give rise to

- INSOLUBLE SILICA in form of Quartz grains
  - which is carried away in suspension by running water and deposited to form SILICEOUS AQUEOUS ROCKS, which include *Sands*, *Gravels and Shingles*, *Sandstones*, *Grits*, *Conglomerates*, *Breccias*.
- INSOLUBLE ALUMINIUM SILICATE
  - which is carried away in suspension by running water and deposited to form ARGILLACEOUS AQUEOUS ROCKS, which include *Kaolin*, *Clays*, *Mud and Silt*, *Mudstone*, *Shales*.
- DISSOLVED SILICA
  - which is extracted from solution in water
    - (*a*) BY PLANTS, to form *Diatomaceous Earths*, and *Tripoli Powder*.
    - (*b*) BY ANIMALS, (*Radiolaria* and *Sponges*) to form *Radiolarian Earths*, *Sponge Spicules*.
    - (*c*) BY CHEMICAL MEANS, to form *Siliceous Sinter* or *Geyserite*.
- DISSOLVED CALCIUM CARBONATE
  - which is extracted from solution in water
    - (*a*) BY PLANTS (*Algæ*), to form *Coccospheres*.
    - (*b*) BY ANIMALS, (*Foraminifera*, *Polyzoa*, *Calcareous Sponges*, *Corals*, *Echinoderms*, *Molluscs*, etc.), to form *Coral Rock*, *Chalk*, *Limestones* (of various kinds).
    - (*c*) BY CHEMICAL MEANS, to form *Travertine*, *Stalactites*, *Stalagmites*, *Oolites* and *Pisolites*.

Organic Rocks formed of Remains of Land Plants.

PEAT.	LIGNITE.	COAL	ANTHRACITE
Carbon 60 per cent.	Carbon 68 per cent.	Carbon 85 per cent.	Carbon 94 per cent.
sp. gr. ·55.	sp. gr. 1·04.	sp. gr. 1·40.	sp. gr. 1·50.

Metamorphism includes those changes in rocks which cause it to completely lose its original texture and to become crystalline. Two kinds of metamorphism are recognised, *Contact metamorphism* and *Dynamo-* or *Regional-metamorphism.*

Contact metamorphism results from the intrusion of great masses of plutonic igneous rocks into the fissures, or between the beds of the superincumbent stratified rocks.

Dynamo- or Regional-metamorphism is brought about by the action of enormous pressures from the sides, which is generally the outcome of slow movements of the earth's crust or crust-creep.

Metamorphic Rocks.

Resulting from
CONTACT METAMORPHISM
(*a*) From clays and shales.
Clay-slates,
Phyllites,
Porcellanite and Lydian-stone.
(*b*) From sands and other siliceous rocks.
Quartzite,
Quartz-schist, (p. 216).
(*c*) From calcareous rocks.
Marbles,
Crystalline Limestones.

Resulting from
REGIONAL METAMORPHISM.
(*a*) Cleavage rocks.
Slates.
(*b*) Foliated rocks.
Horneblende-schist,
Mica-schist,
Argillaceous-schist (including *whet-stone, hone-stone, &c.*),
Gneiss.

QUESTIONS ON CHAPTER X.

(1) Describe three common types of each of the following :—
(*a*) Volcanic rocks, (*b*) aqueous rocks, (*c*) plutonic rocks, and (*d*) metamorphic rocks.

(2) Give an account of the manner in which calcareous rocks are formed by the agency of plants and animals.

(3) (*a*) State the chief differences in chemical composition of the principal types of igneous rocks.
(*b*) How do aqueous rocks differ in composition?
(*c*) What is the chemical composition of the chief varieties of metamorphic rocks?
(*d*) Explain how aqueous rocks may be derived from igneous and metamorphic rocks.

(4) State what you know concerning the plants and animals that separate silica from its state of solution in water, and thus build up siliceous rocks. Give examples of rocks formed in this way.

(5) Name the corresponding plutonic and volcanic rocks which are of (*a*) acid, (*b*) intermediate, and (*c*) basic composition, stating the minerals which are usually present in each.

(6) In what rocks are the following minerals found :—Hornblende, plagioclase, enstatite, and diallage ?

(7) How may igneous rocks be classified ? Name any advantages or disadvantages pertaining to the various systems you name.

(8) Give briefly the leading features of granite, trachyte, diorite and basalt.

(9) In what circumstances do you suppose the rocks known as lavas were formed ? Name three lavas, and say what minerals you would expect to find in each.

(10) Explain the term "plutonic" as applied to igneous rocks. Give the names and mineral constituents of three plutonic rocks.

(11) Compare in general terms the structure of volcanic and plutonic rocks, and account for the differences you name.

(12) What are the general results of the action of the weather on igneous rocks, and how are these brought about ?

(13) What rocks are formed from the insoluble, and what from the soluble products of the decomposition of igneous rocks ?

(14) What are the minerals usually present in granite and basalt respectively ? State what you know of the chemical composition of each of these minerals.

(15) Name the minerals which are present in :—
(*a*) Hornblende-granite.
(*b*) Common basalt.
(*c*) Crystalline limestone
(*d*) Hornblende-schist.

CHAPTER XI

THE EARTH'S CRUST

PHENOMENA CONNECTED WITH THE INTERNAL HEAT OF THE EARTH

Distribution of Temperature in the Earth's Crust.— The student has become familiar with the conception of an originally molten earth, which is now to be regarded as a cooling globe, in which the lowering of temperature has been going on for a long time and been carried to a very considerable extent. He is also aware of the evidence upon which geologists rely for such a belief.[1] There is everywhere a gradual increase of temperature, after the depth at which the influence of the variations in the amount of heat absorbed from the sun is passed, as the depth into the earth's crust is augmented. The depth at which seasonal changes of temperature are felt varies considerably from place to place. The zone of invariable temperature is higher in equatorial regions than in temperate latitudes. In Britain the effects of the fluctuations of the mean temperature throughout the year are observable to a depth of 70 feet. In Siberia, on the other hand, the soil is perpetually frozen down to a depth of 700 feet.

That there is an increase in temperature as a descent is made towards the centre of the earth has been known for upwards of 200 years. Kircher made observations in this connection as far back as 1664. In later years Genssane and Daubuisson made similar experiments, while since 1867 a Committee appointed by the British Association has been doing continuous and elaborate work in this connection. The average rate of increase of temperature may be taken as 1° for every fifty or sixty feet of descent; the British Association Committee give 1° F. for every 64 feet as a mean value. When there is any considerable departure from this average result it can generally be explained by some abnormal circumstance. Among such disturbing influences may be mentioned the neighbourhood of hot springs, of great intrusions of igneous rock, or the proximity of some other form of volcanic activity. The effect of such volcanic action is felt for a long time after the original outburst, as would be expected from the conditions under which cooling takes place; indeed, it has been estimated that an increase of temperature would be observed for several thousand years after such an intrusion of molten material or other volcanic manifestation. But other causes are at work which go far to explain the variations in the increase of temperature which have been noticed. These include such facts as the varying conductivities for heat possessed by different rock materials. Forbes observed, in a series of experiments carried out by him in the neighbourhood of Edinburgh, that the more porous rocks conducted heat very much more badly than compact crystalline materials. He further proved that heat was conducted much more easily in some directions than in others. As a rule heat passes across planes of stratification with difficulty, whereas it is conducted along the mass of any given stratum quite easily.

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[1] *Physiography for Beginners*, pp. 313, 314.

Geoisotherms.—The general consequence of all these variables is that the *isogeotherms or geoisotherms*, that is, the *lines of equal earth temperature*, are by no means parallel, either to the contour of the surface of the earth's crust, or even to the zone of constant temperature referred to above. But as a rule the parallelism between the geoisotherms increases with the depth. The effect of mountain masses and great valley depressions upon the distribution of the lines of equal earth temperature must be noted. Vertically below the summit of a mountain the distance between successive lines is, owing to the increased radiation from the sides of the mountain, greater than the average; while for a contrary reason, vertically below the valley depression the geoisotherms are more crowded than usual. The ultimate condition of things will therefore be that at a sufficient depth below the mountain and valley the parallelism of the lines of equal temperature will be resumed.

Methods of Determining Temperature in Mines, Boreholes, etc. — The form of thermometer used in the measurement of these temperatures was described in Chapter III. It will only be necessary for us to consider here the precautions adopted to ensure accuracy, the neglect of some of which is very probably the explanation of many of the discrepancies between the results of different observers. In the case of boreholes, no observation of temperature should be made until sufficient time has elapsed for the heat of friction developed by the boring tool to become dissipated. Also, since the boring may become filled with water before its greatest depth is reached, which water may either be due to a colder descending current or a warmer ascending one, it is manifestly necessary that some means should be adopted which will enable the observer to be sure that the water at any particular depth shall have the same temperature as the rocks in the vicinity. This object is secured by the following simple device. Two discs of india-rubber which exactly fit the borehole are threaded on a stick, at a distance from one another equal to the length of the thermometer, which is fixed between them. The apparatus is then lowered to the depth at which the temperature is required. It is clear that the discs of india-rubber prevent any circulation of water, and if the apparatus is allowed to remain in position until the water enclosed has taken the temperature of the surrounding rocks, it is quite certain that an accurate observation of temperature has been obtained.

To ensure accuracy in the results of observations made in mines several disturbing causes must be borne in mind, and means taken to eliminate them. Not only will the temperature be increased by the presence of miners and their lights, by blasting operations, and by the heat of friction and impact in the actual work of the men ; but also by such less evident causes as the heat developed by the compression of the air in the deeper parts of the mine and that generated by chemical action, which is always going on in some part or other of the working, as in the oxidation of pyrites or in the decaying of wood. Further, there will be a general tendency for the air and water introduced from the surface to bring about a lowering of temperature. A common plan adopted, to really obtain the normal temperature of the crust at any given depth, is to bore horizontal holes about two feet deep into some freshly exposed rock surface, and after the heat of friction necessarily developed in this process has become dissipated, to introduce a thermometer of the pattern already described (p. 38), taking care to insert the bulb first. The hole is then plugged to prevent any circulation of air, and when the reading of the thermometer has become stationary it is noted down as the temperature at that depth.

Some Underground Temperature Determinations.—The following results are selected from a table compiled by Professor Everett of the underground temperature determinations collected by the British Association Committee up to 1882.[1] The mean increase deduced from all the results in the table from which we have made selections is 1° F. in 64 feet.

Locality.	Depth in Feet.	Increase in Temperatur (Feet for 1°F.)
Bootle Waterworks, Liverpool	1392	130
St. Gothard Tunnel	5578	82
Talargoch Lead Mine, Flintshire	1041	80
Nook Colliery, Manchester	2790	77
Astley Colliery, Dukinfield	2700	72
Scarle Boring, Lincolnshire	2000	69
Pontypridd Colliery, S. Wales	855	76
Radstock Colliery, Bath	620	62
Grenelle Well, Paris	1312	57
Rose Bridge Colliery, Wigan	2445	54
Boldon Colliery, Durham	1514	49
Whitehaven Collieries, Cumberland	1250	45
Carrickfergus Salt Mine	570	40
Slitt Lead Mines, Weardale	660	34

More recently many further observations have been made in different parts of the world, some of the results are as follows[2]:—

Calumet and Hecla, Lake Superior	4580	223·7
Rand Victoria borehole, Transvaal	2500	82
Port Jackson borehole, New South Wales	2929	80
Wheeling Oil well, West Virginia	4462	71·8

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[1] Brough, *Jour. Soc. of Arts*, No. 2299, vol. xlv., 1896.

[2] *Ibid.*

Dolcoath mine, Cornwall	2124	70
Schladebach borehole, Prussia	5734	65
Paruschowitz borehole, Upper Silesia .	6573	62·1
Comstock lode, Nevada	2230	33

The Interior of the Earth.—The question which will naturally present itself to the student at this stage is—If there is this gradual increase of temperature as the centre of the earth is approached, what is the condition in which the materials there exist? If the average rate of increase of temperature of 1° F. for every sixty-four feet of descent were maintained, the ordinary melting point of the most infusible material known would be reached at a comparatively small depth. It is a matter of easy calculation to see that at twenty miles from the surface, for instance, the temperature would be about 1,750° F.; while at fifty miles a temperature of something like 4,125° F. would be reached, which is far in excess of the melting point of say the metal platinum, which can only be fused in the flame of the oxyhydrogen blowpipe. But the condition of things is not so simple as this. Side by side with this increase of temperature, which, by the way, mathematical considerations have led physicists to believe must diminish with an increase of depth after a certain limit has been passed, we have an ever-increasing pressure. It has been established by experiment that substances which contract on solidifying, as most materials do, have their melting points raised by an increase of pressure; and it is consequently most likely that even at the high temperatures which obtain at the depths we have been considering the rocks are, owing to the enormous pressures, in an unmolten condition. At the same time a sudden release of pressure would cause the rocks to assume the liquid condition.

There are many considerations which enter into the discussion of the question of the condition of the earth's interior which are of too abstruse a nature for the student to understand at this stage of his reading, and we shall only indicate generally the theories which have been proposed. Sir A. Geikie says[1]: "There are only three which merit serious consideration. (1) One of these supposes the planet to consist of a solid crust and a molten interior. (2) The second holds that, with the excep-

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[2] *Text-book of Geology*, 3rd edition, p. 53.

tion of local vesicular spaces, the globe is solid and rigid to the centre. (3) The third contends that while the mass of the globe is solid, there lies a liquid substratum beneath the crust."

Other Evidences of the Earth's Internal Heat.—Such are found, as the reader knows, in the phenomenon of *volcanoes*, *geysers*, and *hot-springs*. These have been dealt with in an elementary manner in our introductory book, but it will be convenient for us here to supplement what was there[1] said on these subjects.

Geysers.—*Geysers consist of fountains of hot water which are intermittently active.* Huge quantities of hot water and steam are suddenly forced up to a great height, and the eruption is followed by a period of rest. In the case of the "Old Faithful" geyser, in the Yellowstone Park of Wyoming, this period of rest is nearly always of about 63 minutes' duration In this remarkable district of the United States a very large number of these geysers occur, scattered over a wide area ; and among them occur, from place to place, pools of hot water, which though boiling in some parts are never projected up into the air. It is usual to refer to these as *hot-springs*, keeping the expression "geyser" for those in an eruptive state of activity. Geysers really only differ from volcanoes in the absence of fragments and molten rock ; they mark a declining stage in volcanic action. Though there are often so many geysers in the same neighbourhood, as in the Yellowstone Park, they are quite independent of one another, as was observed by Geikie in this locality. He remarked[2] that "it seemed to make no difference in the height or tranquillity of one of the quietly boiling cauldrons, when an active projection of steam and water was going on from a neighbouring vent on the same gentle slope."

Geysers are common, not only in the area mentioned above, but also in Iceland, Azores, West Indies, Mexico, and New Zealand.

How Geysers are caused.—The origin of geysers begins to be intelligible if the following considerations are borne in mind. The temperature of water which is being heated in any vessel is generally equalised by convection currents, but in a long and narrow tube this circulation is impeded. Moreover, while water under a pressure of one atmosphere boils at 100° C., boiling at any considerable depth in a narrow tube is only possible, because of the greatly increased pressure, at a much higher temperature. Fig. 86 shows the section of a geyser which is in reality such a tube as we have been considering. On the left of the figure the observed temperatures of the water are given, while on the right are printed the temperatures at which water will boil when subjected to pressures equal to that due to the atmosphere and the water column above the indicated positions. The depths in feet are given by a vertical scale on the right of the figure. The nearest approximation to the boiling point is at a depth of 45 feet opposite to the fissure shown in the figure, where the actual temperature is 2° C. below the temperature at which water can boil under the pressure to which the water is there subjected. If by the continued heating of this layer of water by steam from the fissure it attains the temperature at which it can boil, steam is formed, whose expansive force lifts the superincumbent column of water, causing a slight overflow at the top, which, shortening the column, brings the layer B to the

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[1] *Physiography for Beginners*, chapter xx.

[2] *Text-book of Geology*, p. 237.

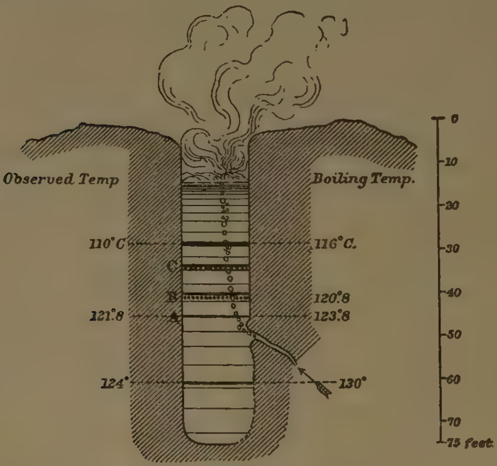

Fig. 86.—Section of a Geyser, showing Fissure supplying Geyser Tube (after Campbell).

position C, where its temperature is above the boiling point at C; wherefore steam is formed at this point and a further lifting and relief of pressure ensues, followed by an eruption.

Composition of the Water of Geysers.—The water erupted from geysers is by no means chemically pure. It contains dissolved in it a great variety of mineral substances, the most abundant of which are silica and compounds of sodium. The solution of the former is, as we have seen, dependent upon the presence of alkaline carbonates, which are among the compounds found dissolved. When the water reaches the surface, and its temperature becomes lowered, it deposits the hitherto dissolved silica in the form of *siliceous sinter* or *geyserite*. It is most probable that certain minute plants of the *algæ* group help in the formation of this sinter, and that it is not wholly the result of evaporation.

Mineral Springs.—Just as the water erupted by geysers contains many mineral substances dissolved in it, so the water of all springs is in reality a solution of a variety of salts. The amount of these dissolved substances as a rule increases with the temperature of the water, and also with the pressure to which it is subjected. Further, as we have before pointed out, the presence in solution of certain substances increases the solubility of salts which are all but insoluble in pure water. Thus, while chalk or calcium carbonate is insoluble in pure water, it is dissolved to a considerable extent by a solution of carbon dioxide, which converts the carbonate into a soluble bicarbonate of lime. Again, if alkaline carbonates have become dissolved in the water, it then has the new power of dissolving previously insoluble silica. *Spring water which contains an abnormal amount of any mineral substance dissolved in it is spoken of as a mineral water, and the spring from which it issues as a mineral spring.*

Some of the commonest of such springs are :—

Calcareous Springs, which contain a large amount of carbonate of lime dissolved. If for any reason there is an escape of the carbon dioxide gas on which the solution of this salt depends, there is an immediate deposition of some of it which takes place round the objects over which the water flows. Sometimes the deposition takes place in sufficient abundance to form a deposit of *travertine* (p. 211). The so-called petrifying springs fall under this heading. They are naturally most abundant in chalk and limestone districts.

Ferruginous or Chalybeate Springs.—These are springs containing a considerable quantity of dissolved compounds of iron, notably ferrous sulphate. The rhombic di-sulphide of iron, known as *marcasite*, occurs in fairly large amounts in some stratified rocks, and is easily oxidised by the weathering action of atmospheric agencies into ferrous sulphate, or green vitriol, which is readily soluble in water. The dissolved sulphate is continually subjected to further oxidation by atmospheric oxygen, which results in the formation of a brownish deposit along the channel of the spring. Such brown hydrates of iron are more abundantly formed, however, in the presence of carbonates, such as calcium carbonate.

Brine Springs are solutions in which sodium chloride or common salt is the principal ingredient. They are very frequent in such districts as those of Cheshire and Worcestershire, where rock salt is found largely developed in the rocks. It is by means of artificial brine springs that much of the salt obtained from Cheshire mines reaches the surface. The deposit of salt is flooded with water, which is allowed to remain in contact with the mineral until it has become saturated, when it is pumped to the surface and the solution evaporated. Brine springs also contain many other salts in solution in addition to sodium chloride. Chief among these are the chlorides of potassium, calcium, and magnesium, and the sulphate of calcium.

Other Mineral Springs contain such substances as magnesium sulphate (Epsom salts); alkaline carbonates (as in the Vichy waters); sulphuretted hydrogen (as in the sulphur waters of Harrogate); and many others.

Mineral Veins.—Under some circumstances the substances in solution in subterranean waters are deposited in fissures in the earth's crust in such a manner as to build up what is known as a *mineral vein.* As to whether these dissolved materials were obtained from the rocks surrounding the fissure, from the overlying strata, or were brought up from below by heated water which has ascended, is not yet satisfactorily proved. There can be no doubt that they owe their origin to the action of water, a fact which becomes clear on examining their general structure. They are usually found in such rocks as the schists, slates, and granites, inclined at from 70° to 80° to the horizontal, and built up of layers of mineral substances belonging to two classes—(1) *Ores*, or minerals, from which the commonly used metals can be extracted; (2) *Veinstones*, or *spars* as they are called when very crystalline, which are much more abundant than the ores. The veinstones which are of most common occurrence are quartz, calcite, fluor-spar; while the ores which are most frequently found are native gold and copper, and such compounds of the metals as oxides, silicates, carbonates, sulphides, etc.

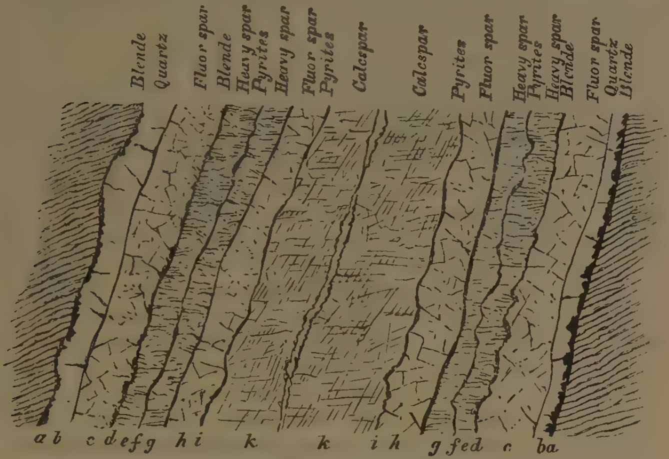

FIG. 87.—Section of a remarkable Mineral Vein near Freiburg. From Phillips's *Ore Deposits* (Macmillan and Co).

An examination of a section of a mineral vein shows that there is a symmetry about the arrangement of its constituent layers. From both of the walls of the vein inwards there is the same succession of deposits. Thus, in Fig. 87, the layer adjoining the wall on both sides of the vein is of zinc blende; this is on both sides succeeded by a deposit of quartz, followed in regular order by layers of fluor spar, heavy spar, pyrites, &c. The explanation of this is that water saturated with these compounds found its way into a hitherto empty fissure, and deposited a crystalline layer of this substance on both walls, which deposition was followed by one of quartz and fluor spar in order. Sometimes it has happened that the fissure has become re-opened, either during the process of filling up or after it was finished. In a few cases water-worn pebbles and shells from above have been found in these mineral veins, affording indisputable proof that during their formation the fissure was in communication with the surface. When there is but one mineral substance present in a vein it is called *simple*, but when it is of the kind we have just described it is *compound*.

VOLCANIC AND EARTHQUAKE PHENOMENA.

Causes of Volcanic Action.—As already explained (p. 229), it will be unnecessary for us to repeat what has previously been dealt with in some detail concerning the kinds of volcanoes, the materials ejected from them, the sequence of events during a volcanic eruption, and the different forms of volcanic cones ; but it will be desirable to explain more fully what are generally regarded as the causes of volcanic action. Though volcanic activity is traceable more or less directly to the internal heat of the earth, there is no geological evidence forthcoming that it was more intense in the earlier stages of the planet's history, when the process of cooling, which is continually going on, was much less advanced than at present. There is, on the contrary, very good evidence that the volcanoes of Palæozoic times were much less intense than those which occurred as recently as the Tertiary epoch.

Whatever may be the final cause of volcanic action, it is abundantly evident that the expansive force of super-heated steam plays an important part in causing an eruption. From the bottom of oceans and lakes, from the surface of the land everywhere, water is continually passing into the crust of the earth. Sometimes by its own weight, and often when the cracks are only minute by capillary attraction, an enormous amount of water must reach the interior. But as we descend the temperature increases, and by-and-by a point is reached at which the water is wholly converted into steam. This temperature will be much higher than the boiling-point of water at the sea-level, because the pressure to which the water is subjected in the earth's interior is very great. Steam will be formed continuously, and thus there will be more and more vapour compressed into a given space, which will cause the pressure to become greater and greater. Just as in a boiler the pressure of the enclosed steam can only be safely increased up to a certain point, beyond which a further addition to the pressure will cause the material of the boiler to break, resulting in an explosion, so the pressure of the steam enclosed within the earth's crust can only go on without an explosion so long as the pressure of the steam upwards is less than that of the weight of the rocks downwards. When the pressure of the steam is increased beyond this point a volcanic eruption takes place.

But there are other gases and vapours besides steam whose expansive force materially assists in the production of volcanic activity. Whether these vapours are derived from the exterior of the earth or whether they are portions of the original vapours of which the earth was in the beginning wholly formed, which were occluded by the liquid materials resulting from the cooling of the gaseous planet, it is difficult to decide.

Some authorities have maintained that a sufficient explanation of volcanic phenomena is to be found in the force of contraction of a cooling globe. If this contraction is supposed to be greater on the outside than in the interior, it is manifest that a continuous tendency for the molten matter within to get squeezed out of weak parts of the crust is set up. We shall see later that volcanoes are arranged in a linear manner along lines of elevation, and it would certainly appear as if there is some connection between the formation of the ridge and the outpouring of molten material.

The late Mr. Mallet, on the other hand, explained volcanic phenomena by the "more rapid contraction of the hotter internal mass of the earth and the consequent crushing in of the outer cooler shell." Referring to this view Sir A. Geikie[1] says: "This ingenious theory requires the operation of sudden and violent movements, or at least that the heat generated by the crushing should be more than can be immediately conducted away through the crust. Were the crushing slow and equable, the heat developed by it might be so tranquilly dissipated that the temperature of the crust would not be sensibly affected in

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[1] *Text-book of Geology*, 3rd edition, p. 268.

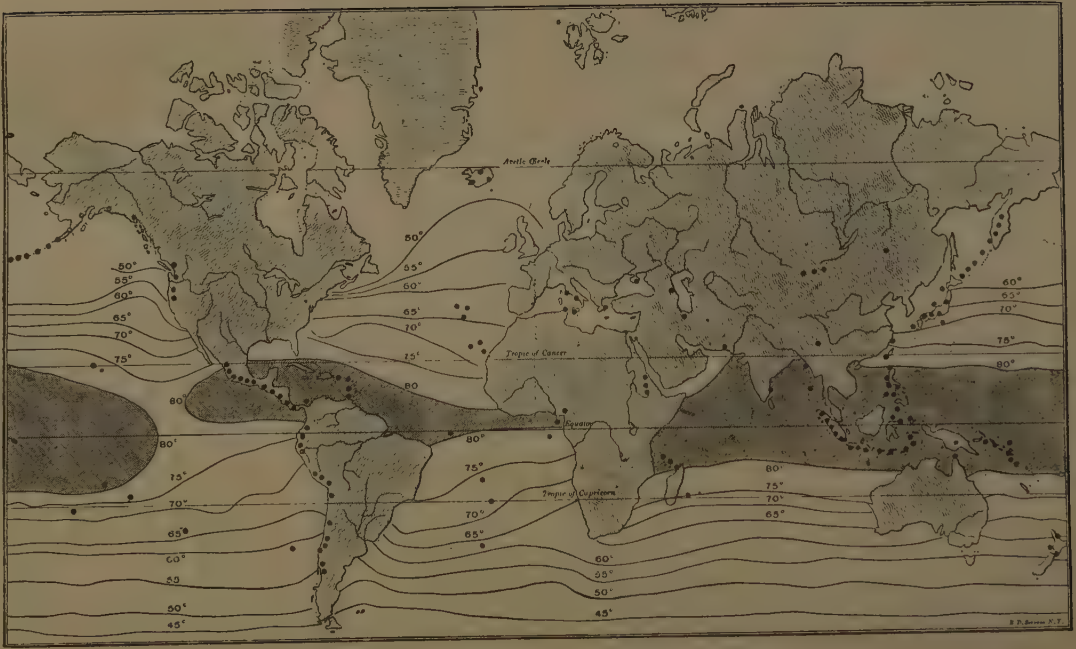

FIG. 88.—Approximate Distribution of Active Volcanoes; also the Annual Isothermal Lines of the Waters of the Ocean Surface. From *Elementary Physical Geography*. By Ralph S. Tarr (Macmillan and Co).

the process, or not to such an extent as to cause any appreciable molecular re-arrangement of the particles of the rocks. But an amount of internal crushing insufficient to generate volcanic action may have been accompanied by such an elevation of temperature as to induce important changes in the structure of rocks, such as are embraced under the term 'metamorphic'."

Several other theories have been proposed by way of explanation of these phenomena; but none of them, nor of those referred to above, are separately sufficient to explain all the observed facts. It is most likely that each of the factors we have referred to, viz., the expansive force of gases and of superheated steam, as well as the varying rates of contraction of concentric zones of the earth's substance, are all of them concerned in the production of volcanic activity.

Distribution of Volcanoes.—Volcanoes generally occur arranged in lines (Fig. 89). This *linear arrangement* is very marked along the coasts round the Pacific Ocean. Many

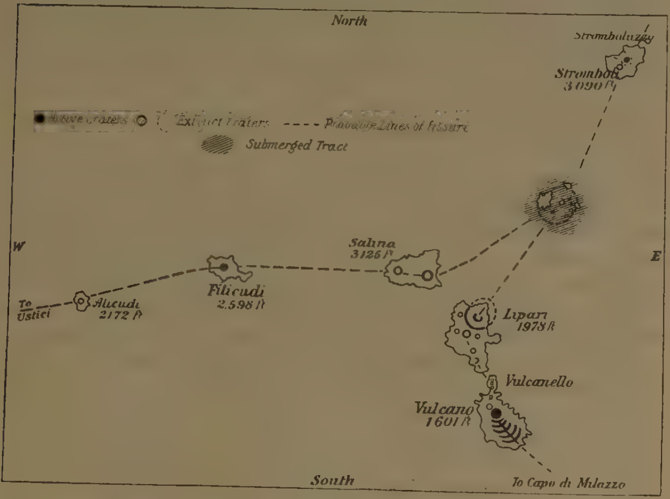

FIG. 89.—The Volcanic Group of the Lipari Islands, showing the linear arrangement of Volcanoes (after Judd).

important active volcanoes, however, are found upon islands. The connection between this *nearness to the sea* and the cause of volcanic action will be at once apparent from what has been said about the part taken by steam in an eruption. The line followed by the manifestations of volcanic activity on the earth can be traced, beginning from the most southerly limit of the American continent, up the western coast of South America following the line of the Andes, through Central America along the west coast of the northern half of the great continent, by way of the Rocky Mountains, into the Aleutian Islands. Thence it passes by way of the Kurile Islands and Japan, all down the western seaboard of Asia, as far as the Malay Archipelago. Here the line divides; one branch passes in a north-westerly direction to Java and Sumatra, the other turns south-eastwards towards New Guinea and passes on to New Zealand.

The line of volcanic activity is not so marked in the Atlantic Ocean. It can be traced from Jan Mayen, through several islands, Iceland, Azores, Ascension, St. Helena, to the West Indies. Nearer home there is a well-marked line in the Mediterranean, along which Stromboli, Vesuvius and Etna occur (Fig. 89).

Earthquake Waves.—It has already been pointed out that *earthquakes are waves of compression in the earth's crust*, and are the result of a to and fro movement of the particles of the crust similar to those which give rise to a sound-wave in the air. The original impulse causing this oscillatory movement is some disturbance, the nature of which has not properly been made out, occurring at depths which have been variously estimated. Whatever its nature, this original impulse causes the particles in its neighbourhood to be violently displaced, and by virtue of the elasticity of the rock this displacement is transmitted from one particle to the next all along the direction of propagation of the wave. The velocity of the wave, depending as it does upon the elasticity of the material through which it is passing, varies very considerably from place to place. These waves are of all degrees of intensity. No collision between the earth and a body coming into contact with it can occur without the production of such a series. Some are exceedingly minute, like those caused by the falling of drops of rain; while others, like those brought about by explosions in mines, which though compared with the first are very intense, yet sink into insignificance by the side of such a wave as that of the great Lisbon earthquake in 1755 Whatever their intensity, we must regard them all as *earth tremors*, thinking of earthquakes as much more violent tremors than any others.

Causes of Earthquake Phenomena.—Though the origin of earthquake waves is referred to a more or less deep-seated disturbance, it is by no means clear what the precise nature of it may be. Possibly it is sometimes caused by the sudden condensation of great quantities of enclosed steam, by some volcanic eruption, by the fracture of rocks deep down in the crust which have been subjected to enormous pressures, or some other cause. There would seem to be, judging from the earthquake shocks which often precede the development of volcanic activity and other facts, some connection between these phenomena. Prof. Milne, a great authority on earthquakes, in a paper[1] to the Royal Geographical Society, in dealing with this subject says: "The greater number of earthquakes may be regarded as announcements that a resistance to secular movement has been overcome, and if such an explanation of earthquake origin is sufficient, then the relationship of the former to the latter is that of a child to its parent. Wherever we find mountains which are geologically young, where the process of rock-folding may yet be in progress, there we find earthquakes. Should these regions of rock-movement be near a sea or an ocean, we also find volcanoes. Volcanic eruptions accompany the generation of steam and gaseous pressure beneath lines of yielding; while earthquakes, if we except a few explosive efforts at volcanic foci, tell us that rocky strata, bending under the influence of terrestrial contraction, have exceeded their elastic limit. Although both may occur in the same country, it is seldom that their origins are close together. In Japan it is seen that active volcanic vents chiefly occur along the backbone of the country which forms the upper edge of a huge monocline (p. 263), whilst the earthquakes are most frequent on the flanks of this fold, or where it sweeps steeply downwards beneath the deep Pacific. The home of the majority of earthquakes is that of the majority of faults, which is a region of monoclinal folding." The same writer argues that if there is a more intimate connection between volcanoes

[1] *Geographical Journal*, vol. vii. No. 3, March 1896, p. 235.

and earthquakes than that of the parentage referred to, it ought to be possible to measure the increased bending which it is natural to suppose would follow the relief of pressure attendant upon a volcanic eruption, and to definitely notice an increase of seismic frequency. Some attempt was made by this eminent observer in Japan, with the aid of delicately adjusted horizontal pendulums; but not only the incompleteness of the observations, but

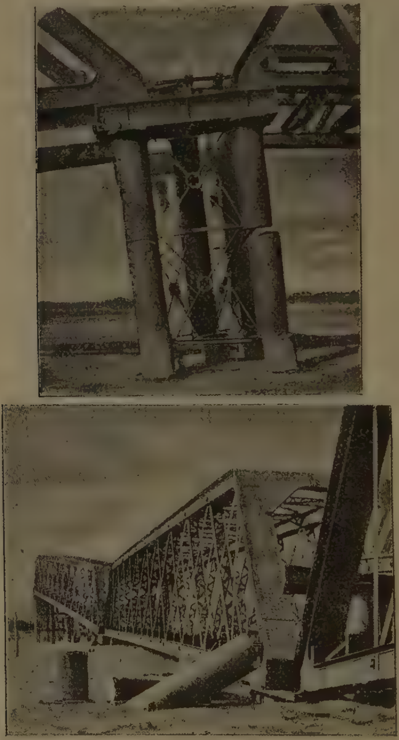

FIG. 90.—Damage done to a railway bridge at Nagara, Japan, during the great Earthquake of October, 1891.

the difficulty of separating the earthquakes of local origin from those happening at a distance, have made the final solution of the inquiry impossible at present.

Distribution of Earthquake Phenomena. — Slight earth tremors are felt everywhere; but the more violent disturbances which are included under earthquake shocks, are much more frequent in some districts than in others. Speaking generally, they occur most commonly in volcanic districts. In the case of the great continent built up of Europe, Africa, and Asia, there is an extensive zone, stretching in an east and west direction, which includes all the countries of the eastern hemisphere where earthquake shocks of any importance are experienced. The western part of this tract of country is bounded on the north by the Alps, and on the south by the elevated lands of North Africa. Its eastern extremity, extending far enough into Asia to include the depressions in which are located the Caspian and Aral Seas, embraces as well the countries of India and Tibet. Many of the volcanoes of the Old World are to be found in different parts of this belt. There is, as we have seen, an almost complete ring of volcanoes round the Pacific Ocean, and it is also round its shores that earthquakes are commonly felt. Earthquakes are most violent where the land slopes precipitously down into the sea; and it is notorious that in Chili and Peru, where the slope is very pronounced indeed, some of the most dreadful earthquakes of which we have any record have been experienced. On the other hand, down the Brazilian coast or along the seaboard of Norway, where the incline is very gentle indeed in comparison, these violent earth tremors are all but unknown. We have previously called attention, in the quotation from his paper, to what Prof. Milne has said about the distribution of earthquakes in Japan (p. 239).

Kinds of Earthquake Waves.—Earthquake shocks give rise to three kinds of waves.

1. The *Earth wave* is that which travels through the land and constitutes the most characteristic feature of an earthquake. The velocity of this wave depends upon the nature of the material through which it is being propagated. The velocity of propagation being directly dependent upon the elasticity of the material (p. 60), it is only natural that earth

waves should travel much more quickly in a compact rock like granite, than in an incoherent substance like sand. The velocity is, indeed, only one-half as much in the latter material. Prof. Milne has shown that the velocity falls off as the distance from the origin of the disturbance increases, and also that the velocity increases with the intensity of such disturbance.

2. The *Water waves*, of which there are two, travel with different velocities. One moves along with the earth wave; the other, much slower one, is developed in the water by "the first sudden blow of the earth wave," and arrives at the shore very much after the earth wave. As it approaches land the wave changes its character, and on reaching shallow water, it breaks and rushes on to the land with terrific violence, causing, as at Lisbon, the most awful damage and loss of life. This is what is commonly, but inaccurately, known as a "tidal wave."

3. The *Air wave.*—When the length of the wave caused in the air is such as to bring it within the range of hearing, it is recognised as a sound wave. This accounts for the noises which accompany earthquakes, and which have been variously described as those of "bellowing oxen," "rolling waggons," etc. But most often these air waves are of too great a length to produce any sensation of sound.

Earthquakes result from a Series of Spherical Waves.—Such a series of waves in the earth's crust is shown

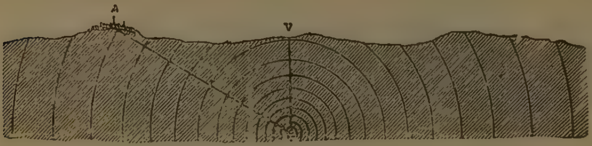

FIG. 91.—Earthquakes result from a series of Spherical Waves.

in Fig. 91. This diagram shows a section of the crust through which the waves are passing. F is the centre of the disturbance, and is called the *seismic centre*, *i.e.* the locality from which the shock originates. The shortest line between this spot and the surface is called the *seismic vertical*, F V. If we know the distance between V and the house A, and also the size of the angle V F A (*the angle of emergence*), it is easily possible to calculate the length of the vertical V F, or the distance of the disturbance beneath the surface. Mr. Mallet has found that this depth is sometimes not much greater than five miles, though observers before him calculated the distance to be sometimes as great as forty miles. The size of the angle V F A can be found by noticing the direction of the cracks formed in the walls of houses and such things. Mallet also found the average velocity of earth waves to be about 789 feet per second, though the value varies from place to place, as we have already described.

Seismometry, or the study and measurement of earthquake shocks, has during recent years, owing to the labours of Milne and others, been very greatly developed. The instruments, or *seismometers*, used in the inquiry all aim at securing "*a point which will remain steady during a shock*"; all that it is then necessary to do is to attach a pen to this point and to arrange that a surface in connection with the shaking ground beneath shall gradually move under the pen. The lines traced by the pen on such a surface will be a visible representation of the movement of the ground. The chief types of seismometric apparatus are classed by Prof. Milne in the following way[1] :—

A. INSTRUMENTS FOR RECORDING SHOCKS.

1. *Seismograph writing on a Glass Disc.*—Here we have horizontal pendulums writing the earth's motion as two rectangular components on the surface of a smoked glass plate. The vertical motion is given by a vertical spring level seismograph. The rate at which the plate revolves is accurately marked by an electrical time ticker. The movements of the latter are governed by a pendulum swinging across and making contacts with a small vessel of mercury. The revolving plate is kept in motion by clockwork, which is set in motion by an electric seismoscope. (Fig. 92, A.)

2. *Seismograph writing on a Drum.*—In this instrument the record is written on a band of paper, the diagram being less difficult to interpret because it is written to the right and left of a straight line and not round a circle.

3. *Seismograph writing on a Band of Paper.*—In this

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[1] *Nature*, February 9th, 1893.

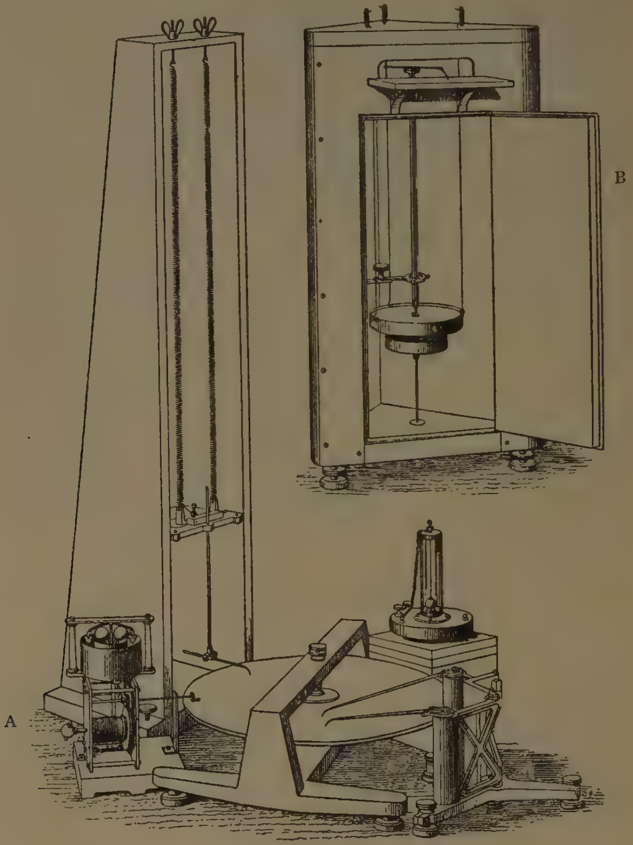

FIG. 92.—Seismometers.

A.—Ewing's Seismometer. The three pens remain steady during a shock while the smoked-glass plate moves with the earth, and traces the record of motions in the direction up and down, east and west, north and south.

B.—Ewing's Duplex Seismometer. The single pen traces the earth's horizontal motions only.

instrument not only is the diagram written along a straight line but it is written with a pencil, the trouble of handling smoked paper being therefore avoided. When the earthquake ceases, the drum ceases to revolve, but if a second or third earthquake should occur, it is again set in motion. By this instrument a series of earthquakes may be recorded, the resetting of the instrument being automatic.

4. *Seismograph without Multiplying Levers.*—This instrument is intended to record large motions, the horizontal levers not being prolonged beyond the steady points to multiply the motion. For large earthquakes, when the ground is thrown into wave-like undulations, special instruments which measure tilting are employed.

5. *Duplex Pendulum Seismograph.*—In this case a steady point is obtained by controlling the motion of an ordinary pendulum with an inverted pendulum. The record consists of a series of superimposed curves written on a smoked glass plate.

6. *Mantelpiece Seismometer.*—This is intended for the use of those who simply wish to know the direction and extent of motion as recorded at their own house. It is a form of duplex pendulum, and it gives absolute measurements for small displacements.

7. *Tromometer.*—This is one form of an instrument which is used to record movements which are common to all countries, called earth tremors. Every five minutes, by clockwork contacts and an induction coil, sparks are discharged from the end of the long pointer to perforate bands of paper which are slowly moving across a brass table. If the pointer is at rest then a series of holes are made following each other in a straight line; but if it is moving, the bands of paper are perforated in all directions round what would be the normal line of perforations.

The earth movements which cause these disturbances are apparently long surface undulations of the earth's crust, in form not unlike the swell upon the ocean.

A more satisfactory method of recording these motions, which has been used for the last few years, is by a continuous photograph of a ray of light reflected from a small mirror attached to a small but extremely light horizontal pendulum.

B. Instruments for Starting the Recorders.

Electrical Contact Makers.—These instruments are delicate seismoscopes, which on the slightest disturbance close an electric circuit, which, actuating electric magnets, set free the machinery driving the recording surfaces on which diagrams are written.

C. Record of Time of Shock.

Clock.—At the time of an earthquake the dial of this clock will oscillate quickly back and forth and receive on its surface three dots from the ink-pads on its hours, minutes, and seconds without being stopped.

The Charleston Earthquake—Co-seismal Lines.—The map (Fig. 93) which accompanies a very interesting paper[1] on this subject by Prof. Edward S. Holden, the Director of the Lick Observatory, California, shows the extent and intensity of the great Charleston earthquake by means of lines joining in *all points where the shock occurred at the same moment*, and which are known as *co-seismal lines*, with the help of a second series of lines joining in *places where the intensity of the shock was the same*, called *iso-seismal lines*. It is highly instructive to notice "the effect of the great mountain chain of the Appalachians, especially in Vermont and New Hampshire. Here the shock was readily transmitted along the axis of the chain. In the neighbourhood of Charleston, however, the chain served to prevent a passage across itself."[2] The calculations, made from the observations taken during the earthquake, show that the velocity of transmission of the earth wave was the greatest ever observed, being no less than 17,000 feet per second, or 193 miles per minute, which is a velocity about six times as great as that of the well-known Lisbon earthquake.

Results obtained in California.—Prof. Holden also summarises the results obtained from a series of observations made in California in the following way:—

1. The motion of the ground usually begins with small tremors, and the maximum does not occur for some seconds.
2. There are usually several maximums, with intervals of comparative rest between them.

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[1] *The Century Magazine*, vol. xlvii. No. 5, March 1894.

[2] *Ibid.*

3. The disturbance usually dies away even more gradually than it begins.

4. The range, the period, and the direction of movement

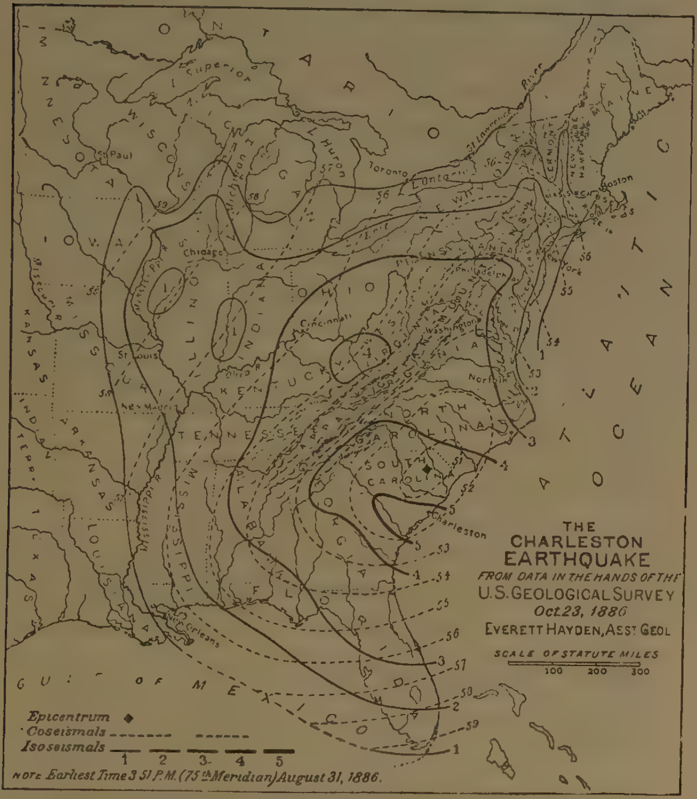

FIG. 93.—Co-seismal and Iso-seismal Lines of the Charleston Earthquake, October 23, 1886. Reproduced from the *Century Magazine.*

are exceedingly and irregularly variable during an earthquake.

5. The whole duration is rarely less than one minute.

6. Even in destructive shocks, the greatest displacement of the soil is only a few millimetres.

7. The period of the principal movement is usually from half a second to a second.

8. The vertical motion is usually far less than the horizontal.

CHIEF POINTS OF CHAPTER XI

Distribution of Temperature in the Earth's Crust.—Below the depth at which seasonal changes of temperature are felt, there is everywhere a gradual increase of temperature as the depth into the earth's crust is augmented. The average rate of increase of temperature may be taken as 1° F. for every 64 feet of descent (B.A. Committee).

Geoisotherms are lines of equal earth temperature. They are parallel neither to the earth's crust nor to the zone of constant temperature; but the parallelism generally increases with the depth.

Condition of the Earth's Interior.—The rate of increase of temperature given above would result in temperatures greatly in excess of the melting points of all known materials under atmospheric pressure at comparatively small depths. But the enormous pressures to which the substances constituting the interior are subjected probably prevent fusion.

Other Evidences of the Earth's Internal Heat.—These are afforded by volcanoes, geysers, and hot springs. The chief characteristics in connection with these phenomena are given in the chapter.

Mineral Springs contain an abnormal amount of some mineral substance dissolved in them. *Calcareous-*, *ferruginous-*, and *brine-*springs are typical examples.

Mineral Veins are symmetrically arranged deposits of different minerals occurring in fissures in the earth's crust. The mineral material has most probably been deposited from water. The minerals are of two kinds:—(1) *Ores*, from which the commonly used metals are extracted; (2) *vein-stones* or *spars* are very crystalline minerals, like quartz, calcite, and fluor-spar.

Causes of Volcanic Action.—Whatever may be the final cause of volcanic action, it is certain that the expansive force of super-heated steam plays an important part in causing an eruption.

Some authorities have maintained that a sufficient explanation of volcanic phenomena is to be found in the force of contraction of a cooling globe.

The late Mr. Mallet maintained that the "more rapid contraction of the hotter internal mass of the earth and consequent crushing in of the outer cooler shell" is a more satisfactory explanation.

Probably all these causes take part in the production of volcanic phenomena.

Distribution of Volcanoes.—Two facts are very noticeable—(1) the linear arrangement of volcanoes; (2) their proximity to the sea.

The line of volcanic activity can be traced from Cape Horn, right up the western coast of the great American continent, through the Kurile Islands, down the east coast of Asia as far as the Malay Archipelago, where it divides into two branches. One goes north-west to Java and Sumatra, the other south-east to New Guinea and New Zealand. There is another line of volcanic activity down the Atlantic seaboard, going from Jan Mayen through Iceland, Azores, Ascension, St. Helena, to the West Indies. A third line includes Stromboli, Vesuvius, Etna.

Earthquakes are waves of compression in the earth's crust caused by (1) the expansive force of steam under pressure; (2) the dislocation of rock-masses beneath the surface.

Earth Tremors are slight shakings continually taking place in the earth's crust; they can be divided into—(1) irregular tremors, due to internal action and faulting; and (2) regular tremors produced by the warming and cooling of the earth's crust by the sun.

Earthquake Waves are the results of disturbances which are rarely at a greater depth than ten miles. They are of three kinds—(*a*) earth-waves, (*b*) water-waves, (*c*) air-waves. Tha velocity of earth-waves varies from about 800 feet per second to about two miles per second; the velocity of water-waves is less than this. Air-waves are generally too long to affect the auditory nerve and so produce sounds.

Seismometry is the study and measurement of earthquake shocks. The instruments used for measuring such shocks are called *seismometers*. They all aim to secure "a point which will remain steady during a shock." Prof. Milne's classification of seismometers is given in the chapter.

QUESTIONS ON CHAPTER XI.

(1) What are geoisotherms? State what you know concerning the position of those within the earth's crust.

(2) How can the rate of movement of earthquake waves be determined by time observations, and what are the chief sources of error in such observations?

(3) (*a*) Draw and describe a form of maximum and minimum thermometer; and
  (*b*) State the approximate reading of such an instrument when it is let down a bore-hole 4,000 feet deep.
  (*c*) When it is let down to the floor of an ocean at a depth of 3,000 feet.
  (*d*) When it is carried up in a balloon to the height of five miles.

(4) What is a geyser, and in what respect does a geyser resemble a volcano? State the points in which geysers resemble and differ from volcanoes and ordinary hot springs respectively.

(5) (*a*) What special forms of instruments are used for determining the temperature of the earth's crust?
  (*b*) How are observations on earth temperatures carried on in mines and tunnels?
  (*c*) How are observations on earth temperatures made in bore-holes and wells?
  (*d*) What are the general results obtained by these observations?

(6) What is the average rate at which the temperature changes in descending below the earth's surface? What circumstances may cause variations in the average rate of change?

(7) What reasons are there for believing that the interior of the earth is very hot?

(8) Write a short essay upon the probable condition of the earth's interior.

(9) Describe how geysers are caused.

(10) Describe two common kinds of mineral springs.

(11) How do you account for the formation of mineral veins?

(12) What are the primary causes suggested to account for the production of volcanic phenomena?

(13) Give a general description of the distribution of volcanoes on the earth.

(14) Give some instances of the linear arrangement of volcanoes.

(15) Describe three kinds of waves which may be produced by an earthquake.

(16) Describe a simple form of instrument for recording earthquake shocks.

(17) How is the velocity of an earthquake determined?

(18) Give a brief account of the principle of the method by which the depth of the place of origin of an earthquake is determined.

(19) What are the chief causes which have been suggested as giving rise to earthquakes?

(20) How has the rate of propagation of earthquake vibrations been determined? What do you know concerning the results arrived at?

CHAPTER XII

THE EARTH'S CRUST

MOVEMENTS IN THE EARTH'S CRUST AND SOME OF THEIR RESULTS

The Great Movements which take place within the Earth's Crust.—The error of regarding the crust of the earth as an example of stability has been already exposed in our introductory book. The popular expression *terra firma* is the reverse of true. We have rather to think of the crust of the earth as being continually subjected to a variety of movements, many of which we have now studied in some detail, while some of the remaining ones have to be dealt with in this section. Those slow movements extending over great periods of time, which we have referred to[1] as *secular*, result eventually in a complete alteration in the contours of the land and water. New stretches of land are formed by the gradual upheaval of the part of the crust forming the floor of the sea, while in other parts the sea encroaches and submerges tracts of country bordering the ocean, as a result of the slow subsidence which has taken effect upon the portions of the crust concerned. The study of the geological record, as revealed by the stratified rocks, convinces geologists that there has been a well-nigh endless recurrence of upheavals and depressions—indeed, we must regard it as an eternal see-saw. Let us select one case from this multitude of instances. The south-east of England is largely built up of a great stretch of chalk, which also extends right across the continent as far as the centre of Europe. Nowhere is there any great departure from horizontality, showing that it has been subjected to no violent movements of the kind we shall be studying immediately. Yet from the identity in microscopic composition between this chalk and the Globigerina ooze, which covers the floor of large parts of the oceans, we know, with certainty, that at one time this large piece of Western Europe must have reposed beneath two or three thousand fathoms of oceanic water, and, by the gentle force of a gradual though irresistible upheaval been raised above the sea-level and there subjected to the sculpturing power of atmospheric denudation. From the consideration of such cases as this we are led to the conclusion that *continental elevation* may be brought about without any extensive fracturing or crumpling of the rocks.

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[1] *Physiography for Beginners*, pp. 324–6.

But, in the words of the late Professor Prestwich, "in all parts of the world these uniformly uplifted areas are bounded by comparatively narrow bands or zones, more or less rectilinear, within which strata have been tilted at high angles and folded and compressed into colossal ridges ; here also the tilting and compression have been accompanied by enormous faulting and wonderful inversions." Though so different in their results, both these sets of movements are traceable to the same common cause, namely, the great internal forces of the earth. In order to more clearly explain the nature of these movements of faulting, crumpling, and so on, we must first call the attention of the student to a variety of arrangements which strata assume in the earth's crust—some of them original, others impressed upon them by subsequent agencies.

Arrangements of Strata. Horizontal Strata.—At the time of their deposition almost all stratified rocks are arranged in layers which are roughly parallel. That they are not strictly so is apparent from the most cursory examination. Nor could it be expected that they would be when the circumstances under which they are laid down are borne in mind. As we have already had occasion to point out, stratified rocks have all been thrown down in water in the order of the specific gravities of the materials of which they are built up. If we imagine a river pouring a quantity of suspended detritus, consisting of mud, sand and gravel, into the quiet waters of a lake, the heaviest gravel is deposited first, and is succeeded by the sand and mud in order, forming a roughly parallel arrangement. Wherever the area over which deposition is taking place is larger, the volume of suspended material greater, and the process of laying down slower, the approach to parallelism is more marked.

It is evident, that in the absence of any disturbance of the strata, those beds which lie beneath must have been deposited before, or are older than, those occurring above. It is in this way the geologist arrives at conclusions as to the relative ages of strata. When deposition has taken place from a stream subject to variable currents of some strength, another arrangement of the strata, known as *false bedding*, is common, as is often seen in sandstones particularly Fig. 94.

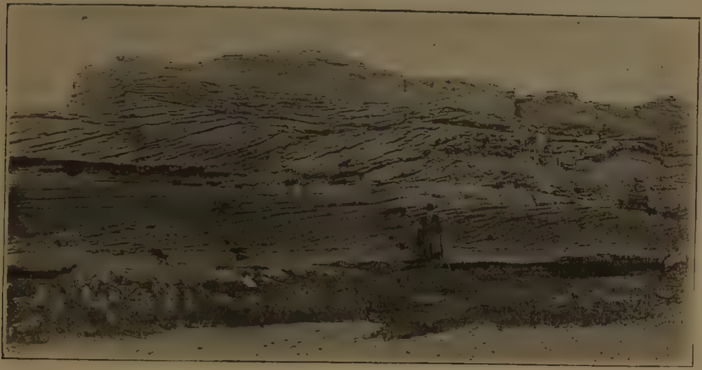

FIG. 94.—The Current Bedded Strata of the Lower Pebble Beds, Middle Hilbre Island, Cheshire. (From a Photograph by Mr. Charles A. Defieux.)

Though geological formations may retain their original horizontal arrangement they have more commonly been subjected to some degree of movement resulting in what are known as inclined and vertical strata.

Other Positions of Stratified Rocks.—When the originally horizontal strata have, in consequence of movements in the earth's crust, been pushed up so as to become inclined at any angle to the horizon, they are called *inclined strata*. When this angle is a right angle the strata are spoken of as *vertical.* In a few rarer cases the order of the beds has been completely reversed, the older, first deposited stratum, coming to lie over the younger later beds; and in such a condition of things we have an example of *inverted strata.* The angle which inclined strata make with the horizon is called the *dip* of the beds. In the case of horizontal formations the dip is, of course, nothing; while that of vertical beds is 90 degrees. In some cases strata lie horizontally or nearly so, upon the upturned edges of other strata, as in Fig. 95. The stratifications thus do not agree with one another, and are therefore said to be *unconformable.*

The extent of a bed which is seen at the surface depends altogether upon the size of the angle of the dip. When a series of strata is truly horizontal, it is apparent that only the uppermost bed can appear at the surface, until, at all events, some part of the one immediately beneath becomes exposed by the washing away of parts of the surface stratum. When beds have become inclined, however, each bed in succession is found at the surface, and the smaller the angle of dip the wider will be the part of the bed exposed. This exposed portion the geologist calls its *outcrop.* The width of the outcrop, then, is least for vertical beds, and in this case only is it an exact measure of the thickness of the stratum. The divisions of the compass to which the outcrop of a stratum points is called its *strike.* We can exemplify all these terms very simply with a heap of books. First arrange them in a tidy pile when they represent horizontal

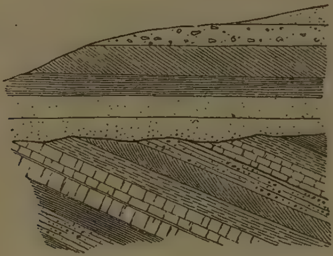

FIG. 95.—Unconformable Strata. From *An Introduction to Geology.* By W. B. Scott. (Macmillan and Co.)

strata. Now push them over so that they lie as in Fig. 96. They now simulate inclined strata. Whereas in the first case only the uppermost book could be seen on the top of the pile, in the second example the top of the row of books is made up of the succession of their front edges. The edge of each book represents an *outcrop;* the direction in which the edge of the book points is its *strike;* while the angle the covers of the books make with the table is the *dip*.

In observing the dip of the individual members of a succession of beds it becomes very noticeable, oftentimes, that there is a gradual diminution in the size of the angle, indicating that, in reality, the exposed parts of the bed are parts of large curves, or folds, into which the strata have been thrown by great movements in the earth's crust.

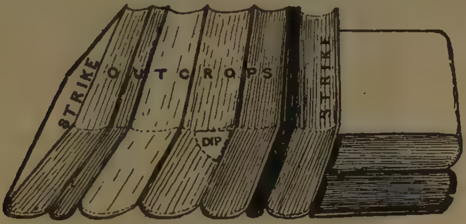

FIG. 96.—To Illustrate the terms Outcrop, Dip, and Strike, applied to Strata.

Folding of Strata.—When subjected to enormous lateral pressures, as horizontal strata are, as a result of those great movements of the earth's crust to which we have made such frequent reference, they become thrown into folds in a manner which can be easily imitated by the following simple experiment :—

EXPT. 30.—Arrange differently coloured rectangular pieces of cloth in a heap, and place a piece of board of the same height as the pile at each end of the heap. Place a third piece of board, or a book of a suitable size, along the top of the pile with a weight on it. Now apply a lateral pressure, by pushing with both hands simultaneously against the end pieces of board, and notice the folding of the layers of cloth.

Anticlines and Synclines.—Where strata dip away *from* the same line, as the pieces of cloth do in the crests of the wave-like folds into which the layers of cloth were thrown in the above experiment, we have what is known as an *anticlinal fola* or *anticline*, the line from which the strata dip being referred to as the *anticlinal axis* (Fig. 97). When, on the other hand, strata dip *to* the same line, as in the troughs of our experiment, we have what is called a *syncline* formed, the corresponding line in this case being called the *synclinal axis* (Fig. 98).

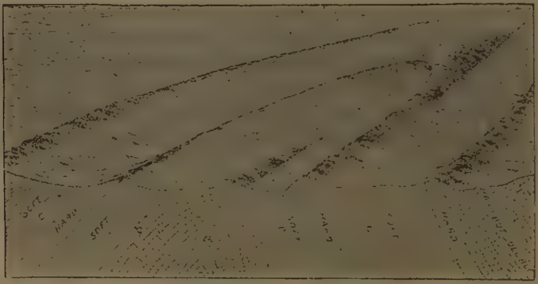

FIG. 97.—Perspective View and Vertical Section of Anticlinal Beds. From the *Report of the U.S. Geological Survey.*

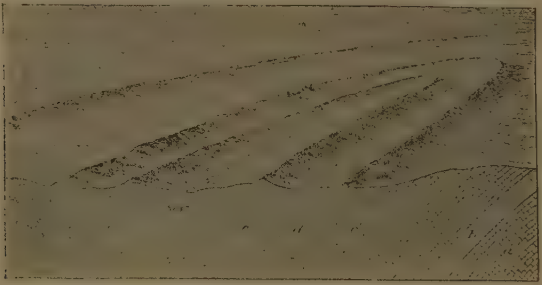

FIG. 99.—Perspective View and Vertical Section of Synclinal Beds. From the *Report of the U.S. Geological Survey.*

Such folding as above described is very common in different places, especially in mountain ranges, which, as we shall see more fully later, probably owe their origin, in a great degree, to tangential pressures, similar in kind though enormously greater in degree, to the force exerted by the hands in Experiment 30. As the student has learnt, folding is only one of the results of forces such as those operating in their production, which also bring about the metamorphic changes dealt with in Chapter X.

Denudation has generally effectually obliterated all evidence of folding which may at one time have been apparent at the surface. The continued wasting brought about by atmospheric agencies and the washing away of material effected by running water, not only remove the top of the anticlines, but also pare down the whole of the folded crust to a more or less dead level.

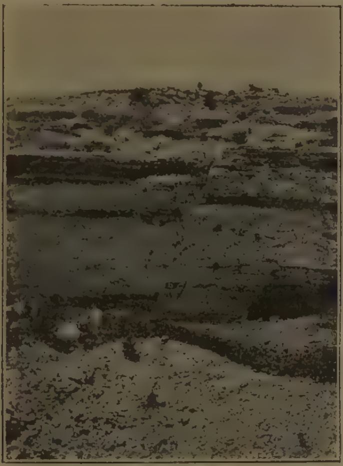

FIG. 99.—A Normal Fault. From Prof. W. B. Scott's *Introduction to Geology.* (Macmillan and Co.)

But where any section is laid bare, as in sea cliffs, railway cuttings, or many other such exposed places, any folding which has occurred becomes easily apparent.

Folding may extend to the structure of individual rocks being sometimes on a sufficiently small scale as to be seen in hand specimens. Many schists and gneisses show such *crumbled* or *contorted* structure.

Faulting.—The results of the great lateral pressures arising from the movements which have from time to time taken place in the earth's crust are not confined to the metamorphic changes and the folding of strata which have been referred to. Sometimes the strata have their limit of tenacity exceeded, and instead of continually bending, they actually fracture under the enormous tangential thrust. Such fractures or breaks in strata are classed together as *faults* (Fig. 100). Under this term of the geologist are included all such practical mining expressions as *slips*, *slides*, *troubles*, *hitches*, and so on. The work of denudation is not relaxed all the time the process of faulting is going on, and consequently there will be no great step occurring at the surface. Indeed, faults are usually only to be recognised by a careful survey of the beds of the district along which the fault runs.

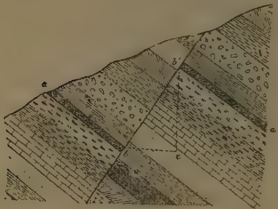

FIG. 100.—Section through Faulted Beds. *b′c*, throw; *bc*, heave; *bb′*, stratigraphic throw; angle *bb′c*, angle of hade; *b′bc*, angle of dip. From *An Introduction to Geology*, by Prof. W. B. Scott. (Macmillan and Co.)

The fractures caused in rocks may be either *vertical* or *inclined*, though they are most commonly of the latter kind. Should the fault be nearly horizontal it is generally referred to as a *thrust plane*. Though we might quite logically speak of the dip of a fault plane, it is usual, in practice, to reserve the name dip for the purpose we have explained (p. 254), and to use the expression *hade* for the inclination of the fault plane to the horizontal (Fig. 100). When the *fault hades to the downthrow*, as miners say, or when the inclination of the fault plane is towards the same direction as that in which the rocks have moved as a result of the break, we have what is called an *ordinary fault*, since this condition of things is most common. When the opposite of this is true we have a *reversed fault* (Fig. 101). The amount of movement which has taken place in the strata, consequent upon faulting, is technically called its *throw*, and is measured by the vertical distance between the two parts of the originally continuous stratum. In the faulting of some rocks the break is so "clean-cut," and attended by so little lateral movement, that it is impossible to thrust a knife edge into the crack.

The rubbing of the fractured surfaces together during the process of faulting often polishes them, producing characteristically striated surfaces, which are known as *slickensides*. When, however, the rocks are soft and crumbling, the material gets broken up and the fault is wider, though generally filled up with the powdered material produced by the crumbling of the rock, which is referred to as *fault rock*.

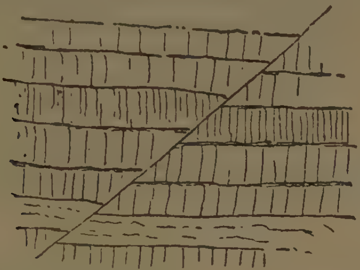

FIG. 101.—Reversed Fault, Faroe Isles (after Geikie).

Faults may be of several kinds. The fault-line may be single and continuous, causing a *simple fault*; or, a succession of small faults may occur in which the faulting planes are parallel and the amount of throw in each case very little, producing *step-faults* (Fig 102); or, two faults may hade towards one another, giving rise to a *trough-fault* (Fig. 103). For a description of other terms having reference to faulting, of which there are many, we must refer to works on Geology.

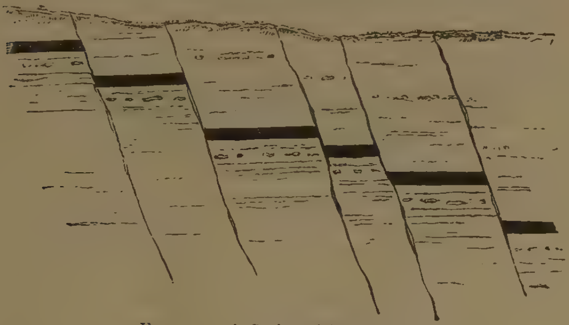

FIG. 102.—A Series of Step-Faults.

Production of Mountain Structures.—Mountains are neither all of the same kind nor formed in the same manner, and consequently an exhaustive discussion of the production of mountain structures is not possible within the limits of such a chapter as this. The interested student is urged to consult one of the many excellent treatises on Geology[1] for a full account of the origin of mountain chains.

The generally accepted theory of the origin of mountain structure may be briefly described in three steps. The first consists in an exceedingly slow and enormously prolonged subsidence of the part of the earth's crust which will eventually be marked by the occurrence of a mountain chain. In this manner, what Prof. Dana has called a *geosynclinal* is formed, consisting of a greatly thickened portion of the earth's crust due to an enormous deposition of sediment during the prolonged subsidence. Then the actions comprised in the second step of the process come into play in the form of immensely powerful lateral or tangential thrusts, which throw the crust into huge folds (Fig. 106), also producing faulting and metamorphic changes, and resulting in the production of what are known as *geanticlinals*. Finally, the persistent influence of the weathering and denuding actions of atmospheric agencies cause the upheaved ridge to become sculptured into the characteristic and picturesque forms whic hwe associate with mountain ranges.

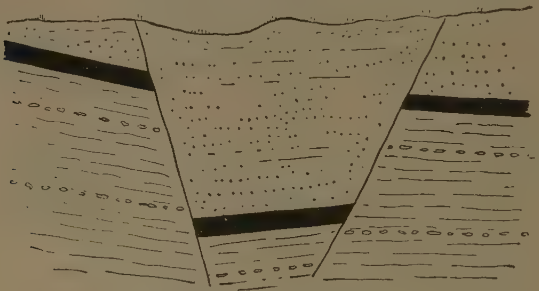

FIG. 103.—A Trough Fault.

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[1] See, for example, *The Student's Lyell*, by Prof. Judd; and *Manual of Geology*, by Prof. Dana, 4th edition, 1895.

Such a description as this must be regarded as the barest outline. We have made no reference to the various opinions which have been expressed as to the cause of the tangential thrusts of which we have spoken in the second step of our brief sketch. It must suffice for us to say that some authorities maintain that the force of contraction in a continually cooling crust is the initial cause of the lateral pressures whose agency is invoked to explain the folding which produces mountain ridges; while others allege that the heating which the accumulated sediment, referred to above, experiences as the continued subsidence brings it into regions of higher and higher temperature, causes an expansion in an upward direction and a subsequent lateral pressure. Added to which there is the fact that the layers of sediment as they are carried lower and lower

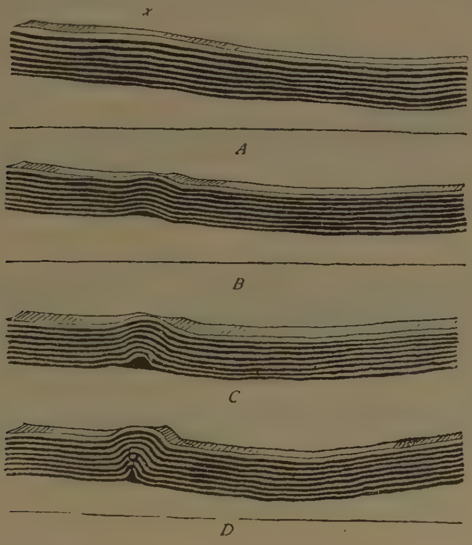

Fig. 104.—Model Showing Effects of Lateral Compression. *A*, before folding, with slight initial dip at *x*; *B.C.D.*, in various stages of Compression. From *An Introduction to Geology*, by Prof. W. B. Scott. (Macmillan and Co.)

are compelled to occupy a smaller and smaller superficial area with a similar result.

Prof. E. Reyer has maintained,[1] however, that folding "does not depend on a contraction of our planet, but is a simple gliding phenomenon." He has illustrated his views by an interesting series of experiments, with models of variously coloured clays arranged upon inclined planes. In this manner he has obtained some excellent imitations of folded and contorted strata. Prof. Reyer's theory will be best understood if we follow him in describing the essential steps in the origin of an ideal mountain chain. Fig. 105, *a*, is a reproduction of the initial condition of things. S is the line of coast along which is shown a series of sediments (S to X), thicker towards the land, which is marked black on the extreme left of the figure. The shading above X represents the waters of the sea. The next stage in the process is shown in Fig. 105, *b*, where it is seen that sliding and folding have occurred, the sediments being meanwhile raised above the sea level as shown at O. Then the subaerial agencies begin their work of erosion, which eventually becomes so extensive that as a consequence it is accompanied

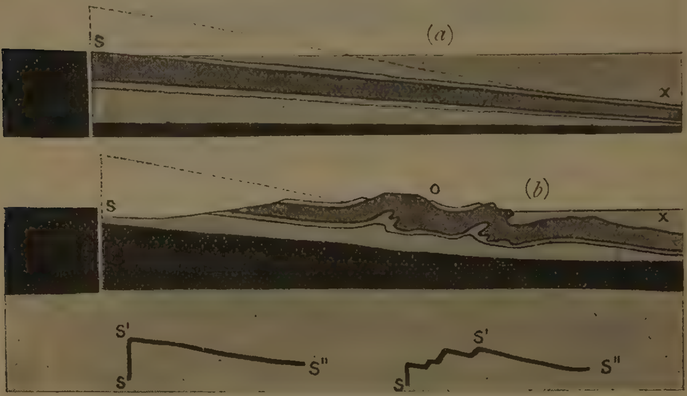

FIG. 105.—To Illustrate Prof. Reyer's Theory as to the Mode of Formation of Mountain Chains.

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[1] See *Nature*, July 7th, 1892.

by cooling and subsidence, which is often in its turn followed by faulting, giving rise to structural forms of the general patterns shown.

Mountains due to other Causes.—On the other hand, mountains are sometimes the result of causes quite distinct from those we have just described. In some cases volcanic action has been instrumental in building up cones of one form or another all along a line of weakness, as in the case of the range of the Andes, which essentially consists of a chain of volcanic mountains.

The so-called *hills of circumdenudation* have been brought into existence by varying amounts of erosion in rocks of different degrees of hardness brought about by streams and atmospheric agencies. *Table-lands of erosion* owe their origin to causes of a similar kind.

Types of Mountain Flexures.—Following Sir Arch Geikie,[1] we may divide the patterns followed by mountain ridges into several classes :—

(1) *Monoclinal Flexures.*—In an anticline (p. 256), as the reader knows, there are strata dipping from both sides of a central anticlinal axis. If we have one set only of these highly inclined strata occurring, which within a short distance resume their horizontal form, the arrangement is known as a *monocline.* A beautiful instance is found at Alum Bay, near the Needles in the Isle of Wight. Several of the minor mountain ridges of the world are of this nature, as, for example, those bordering the table-land of Utah.

(2) *Symmetrical Flexures.*—Under this heading fall the well-known types of mountain structure seen in the Jura Mountains (Fig. 106) and the Appalachians. A succession of anticlines with corresponding synclines cause parallel ridges with intervening valleys to follow one another in regular order. The sculpturing, which is the outcome of denudation, causes, in some cases, a certain amount of interference with the simple condition of things we have pictured, but, essentially, symmetrical flexures may be regarded in the way stated.

(3) *Unsymmetrical Flexures.*—These, too, are of common occurrence in the Jura Mountains (Fig. 107) and Appalachians. They differ from the last type in as far as one side of the

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[1] *Text-book of Geology*, 3rd edition, pp. 1072–1079.

anticline is more highly inclined than the other. The steeper side points away from the area of maximum movement.

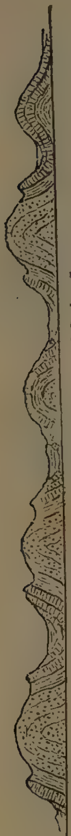

FIG. 106.—Symmetrical Flexures of Swiss Jura.

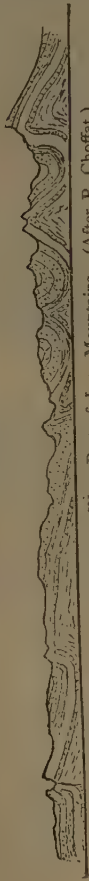

FIG. 107.—Mountain Structure—West Part of Jura Mountains. (After P. Choffat.)

(4) *Reversed Flexures.*—In these the strata "on both sides of the axis of curvature dip in the same direction." They doubtless result from ordinary symmetrical anticlines and synclines, in which the anticlinal and synclinal axis planes are vertical. These planes, becoming more and more inclined as the folding is carried further, causes a strain on the "middle limb" of the fold, and eventually results in elongation, and not uncommonly in fracture. If the lateral pressure continues to act, it gives rise to a typical thrust, "which is nothing but a greatly exaggerated reversed fault."

(5) *Alpine Type of Mountain Structure.*—A mountain range such as the Alps is characterised by its complexity of structure. Inversions, which are frequent, are evidence of the extreme nature of the movements of folding which the district has experienced. They are, moreover, not caused by one but by a succession of upheavals, and it is not, as a rule, hard to trace the successive movements which have taken place. The student would do well to read the account which the eminent authority we have cited gives of the formation of the Alps and the Rocky Mountains.[1]

EARTH-SCULPTURE.

Action of Rain.—Rain has a twofold action upon the rocks at the surface of the earth; it dissolves some of the constituents and also washes away the lighter insoluble ingredients. Its power of

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Ibid., pp. 1077, 1078.

dissolving rocks is considerably increased by the presence in it of gases which it dissolves in its passage through the air. The two gases which are most powerful in this direction are oxygen and carbon dioxide. The dissolved oxygen is particularly active in bringing about chemical changes, known as oxidation, which indirectly causing the decomposition of rocks, facilitate the process of solution. The carbon dioxide, as we have before pointed out, converts insoluble carbonates into soluble bi-carbonates, in this way causing, amongst other similar results, the solution of calcium carbonate. The amount of calcium carbonate which thus becomes dissolved is in some limestone districts very great. The consequence is that large caverns are carved out of the limestone, which is itself composed of calcium carbonate.

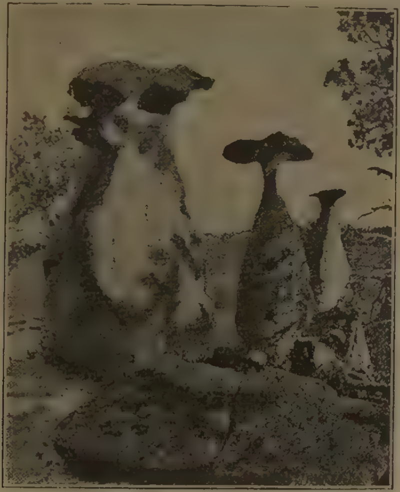

FIG. 108. Earth-Pillars, Garden of Gods, Colorado. Soft rock protected from destruction by caps of harder rock. From Tarr's *Physical Geography*. (Macmillan and Co.)

The formation of *soils*, and the layer of decomposed rock occurring immediately beneath these superficial layers, known as *sub-soils*, is partly traceable to the action of rain. The other potent influences concerned in their formation are vegetation and certain lowly land animals, chief among which is the earth-worm.

An interesting example of the total extent of the rain's activity in earth-sculpture is seen in earth-pillars, like those of the Tyrol and elsewhere. The surface rock in the district where these pillars abound is either a soft clay or shale which is easily worn away. Sprinkled over the surface, however, are lumps of hard rock on which the rain has little or no action. These serve to protect the soft material underneath them, and the result of the continued action of the rain is to produce pillars of the soft clays, each protected by its own covering of hard rock (Fig. 108).

The so-called *Grey Wethers*, which are very common in Wiltshire, and get their name from their likeness at a distance to a flock of sheep, consist of blocks of sandstone etc. They are sometimes of a considerable size, as in the blocks composing the Stonehenge Druidical remains. They represent fragmentary remains of a stratum which extended all over the area where they are now abundant, the greater part of it having been removed by the solution and washing away effected by the rain.

Sculpturing Action of Rivers.—Like that done by rain the work effected by rivers is of two kinds, viz., *chemical* and *mechanical*. The former is very much less important than the latter, but is at the same time very considerable. The amount of dissolved material contained in the water of rivers represents the work of solution effected by them. This amount is, since the amount of water is less, greater in summer than in winter. Taking the river Thames as an example, it has been found that analyses of samples of Thames water give the following results :—

Total solids in grains per gallon	18·24 to 21·63
Total lime " " " "	6·89 " 8·74
Temporary hardness (calcium carbonate).	13·0 " 15·9
Permanent " " " . .	3·3 " 4·4

Knowing the amount per gallon of dissolved material in Thames water, we can, if we know the area of a section of the Thames at a given place, as well as its average rate of flow, calculate the total amount of material carried down in solution by the water of this river. The area of the section of the river has been found by first determining the average of a good series of soundings at Kingston, which gives the mean depth of the river at that place, and then finding the product of this result and the river's breadth, which gives the area required. The average rate of flow of the Thames at Kingston has been determined from observations of the rate made by Messrs. Harrison and Beardmore. The former observer, whose work extended over eleven years, calculates that 1,353,000,000 gallons of water pass Kingston daily; while the latter gives, as the mean of observations extending over eighteen years, 1,145,000,000 gallons per diem. If we take as an average the number 1,250,000,000 gallons daily, we can easily determine the total amount of material carried down by the river in solution. Let us take the average amount in solution as 19 grains per gallon. Then the result will be found from the expression[1]

$$\frac{1{,}250{,}000{,}000 \times 19}{7{,}000 \times 2{,}240} = 1{,}515 \text{ tons daily.}$$

This 1,515 tons is made up as follows:—

Calcium carbonate	1,000
Calcium sulphate	250
Magnesium carbonate	200
Chlorides, sulphates of potassium, sodium, etc.	65

Taking into account certain other modifying influences we shall be more correct, probably, if we assume 2,000 tons daily as about the amount of dissolved material which passes London in the waters of the Thames.

If this rate of solution extended over one million years it would represent an amount of dissolved material which would build up a piece of land sixty miles long, thirty miles broad and one hundred feet thick. This large amount of matter is obtained from the Cotteswold Hills and neighbourhood, which are largely composed of oolitic limestone, and the amount which would be carried away in the time specified above would lower the area seventy-six feet.

The mechanical work done by rivers can best be considered as consisting of three sorts of work,—1. The transportation of loose materials such as mud, sand, gravel, and larger stones from one place to another; 2. The erosion or wearing away of the rocks over which the river passes by the friction of the materials it carries; 3. The deposition of the substances named in lakes and in the sea, thus forming new beds of rock which in time become hardened to form new geological formations.

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[1] There are 7,000 grains to the pound avoirdupois, and 2,240 lbs. to the ton.

Excavating Power of Rivers.—This is referred to under the second of the headings given in the previous paragraph. We must refer the student to our elementary book[1] for an account of the transporting power of rivers, while the formation of new beds of rock from these transported materials will be referred to later.

By far the greatest part of the work of erosion effected by rivers is accomplished by the fragments held in suspension and those pushed along the bed of a strain.

In those cases where eddies are produced in the course of a river, the loose fragments carried by it are whirled round and round, and produce hollows, called *pot-holes*, in the river's bed.

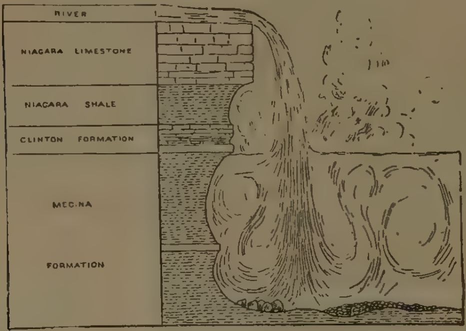

FIG. 109.—Falls of Niagara. Section of the Rocks at the Horse-shoe Fall (Gilbert).

The most important factor determining the extent to which this wearing away goes on is, however, the nature of the rocks over which the river flows. Hard rocks will be excavated to a much smaller extent than soft ones. One of the best examples of this is afforded by the renowned Falls of Niagara, which are situated between Lake Erie and Lake Ontario. The river flows from the former lake to the latter, and passes over a series of beds arranged as shown in Fig. 109, which shows a section of

[1] *Physiography for Beginners* p. 269.

the rocks at the Horse-shoe Falls. It is at once seen that the bed of the river is formed by the hard Niagara limestone which overlies the softer shales and sandstone. The water as it rushes over the fall dashes against the underlying softer rocks, and wears them away at a great rate, thus undermining the limestone, which eventually by its own weight falls into the rapids below, and is washed away. That this kind of action has been going on for some time and at a rapid rate, is clearly shown from the following considerations. At Queenstown, seven miles distant from the Horse-shoe Falls, the limestone mentioned above forms an inland cliff, or *escarpment*, and a deep trench extends from this place back to the falls (Fig. 110). An examination of the nature of the gorge makes it abundantly evident that the river has, by a continued action in the manner described, eroded a channel seven miles in length. Careful observations made from time to time give as the yearly amount of erosion at these particular falls 2 feet 2 inches. From 1848 to 1890 no less an amount than 275,400 square feet of rock have been washed away.

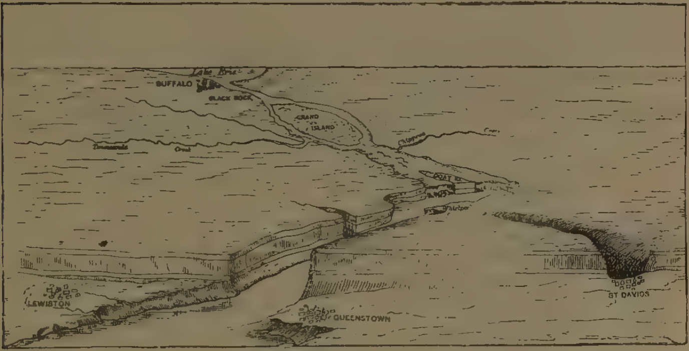

FIG. 110.—Bird's Eye View of the Niagara Falls. (Gilbert).

We must not leave this part of the subject without some reference to the magnificent instance of river erosion which is afforded by the cañons of Colorado. These cañons are gorges with nearly vertical sides, cut out of horizontal beds of soft rock by the river found at the bottom of the ravine. The rocks on either side of the natural cutting correspond exactly, and if there were any doubt of the horizontal nature of the strata, it would be at once set at rest by the consideration that inclined beds would, by the continual tendency to slip, eventually slide down into the river, thus eventually destroying the remarkable perpendicularity which characterises these cañons.

Sculpturing effected by Glaciers.—From the nature of a glacier, with which our reader is already familiar, it can perform no appreciable amount of chemical work; but the work of a mechanical kind which it accomplishes is very important, and can be considered under two heads: (1) its carrying work; (2) the erosion it effects. Though we are here chiefly concerned with the latter kind of activity, it will be well to remind the student that the work of transport is performed in a different way from rivers, for most of the detritus is carried upon the surface of the glacier. Frozen into the mass of the glacier will also be fragments of rock which were disseminated throughout the snow from which it was formed. Moreover, the glacier also slowly pushes along a certain amount of detritus at the bottom, which has for the most part got there by tumbling down crevasses. This rubbish, which accumulates on the surface of a glacier, constitutes the *lateral* and *median moraines*. The material which tends to collect in those places where projections occur in the glacier's bed make up what are called *moraines profondes*. Blocks of a considerable size left on the sides of the valley along which the glacier moves by the melting of the ice of which it is composed are called *perched blocks*.

The earth and stones which often, as we have seen, find their way down crevasses to the bottom of a glacier become firmly frozen into its mass, and as the ice-sheet moves slowly down the mountain side these are ground against the rocky bed, becoming themselves characteristically smoothed and scratched and also causing the same result upon the beds over which they pass. This polishing effect is so great that even the hardest rocks are grooved and striated. The motion of the glacier being generally regularly downwards, these scratches usually indicate the line of motion and stretch lengthwise down the valley (Fig. 111).

When by a general increase of temperature the glacier as a whole melts, its valley is seen to have assumed the form of smooth undulating prominences, in appearance not unlike the back of dolphins as they appear at the surface of the water in which they are rolling. These rounded mounds are called *roches moutonnées*, from a similar likeness they exhibit to the backs of sheep.

The water formed from the local melting ot a glacier collects on the surface and often finds its way down one of the numerous crevasses, carrying with it a considerable quantity of the moraine detritus. This water finally gets under the glacier, and in many cases, by the help of the stones it carries with it, erodes a kind of pot-hole, which is in some places spoken of as a *giant's kettle*. As was pointed out in describing the same sort of work in the case of rivers, the largest amount of erosion will be effected in those cases where the rocks are soft. It is sometimes indeed sufficiently extensive to form considerable hollows, which on the retirement of the glacier often becomes filled with water, forming *tarns* or *lakes*.

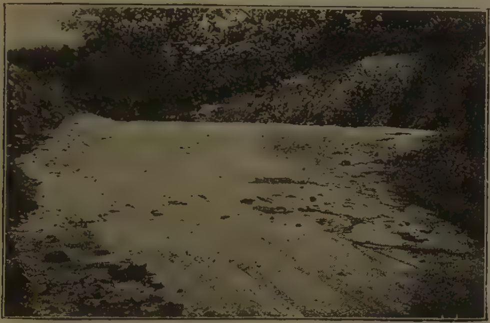

FIG. 111.—Glacial Striations at Kingston, Ohio.

Results of Glacial Action.—The student will readily perceive that it is quite possible to tell where glaciers have been from the permanent record they leave behind. We can summarise the occurrences, the existence of which in any country can be taken as proof of the previous existence of glaciers.

1. The heap of materials formed at the glacier's foot where it began to melt, which contains striated stones, and is known as the *terminal moraine.*

2. The smooth glaciated rocks which formed the bed of the glacier are unmistakable. The striations found thereupon are more or less parallel, and show the direction of the glacier's flow.

3. Perched blocks often occur on what was originally the side of a glacier. They are quite dissimilar in nature from the rocks on which they rest.

4. The material at the bottom of the glacier (*moraine profonde*) is strewn irregularly over the site of the glacier, and contains characteristically striated stones, the mixture constituting *boulder-clay.*

Sculpturing of the Land by the Ocean.—It is clear that this occurs almost entirely along the coast line of the continents. The ocean currents and movements of the sea other than those on the beach have little, if any, effect in wearing away the land. The work of the *Challenger* Expedition has shown that the floor of the deep parts of the ocean is covered with a fine muddy deposit, which it is quite evident would not remain undisturbed were there any very perceptible movements of the oceanic waters. In those parts of the ocean sufficiently near to the land for their waters to hold sand or other material in suspension, any movement on their part will bring about a certain amount of wearing away of the sea-floor, but nothing of any great importance. The bulk of the destructive work accomplished by the sea is above low-water mark. Its extent is generally greatly magnified, the estimates which have been formed of its amount have been exaggerated as a result of dwelling too much upon the activity of the ocean during storms. The work which is accomplished by the sea is of several kinds. First and foremost is the work of erosion effected by the waves, which, dashing against the cliffs, hurl any loose material within their reach with a violence which is ordinarily very great, and during storms simply stupendous. The noise of shingle being moved in this manner can be heard at a distance of several miles. Not only are the cliffs broken and worn into stacks, buttresses, and needles (Fig. 112), but the stones themselves are ground and worn until they assume the size and smoothness with which all visitors to the western watering-places of these islands are quite familiar.

Naturally, the extent of this erosion will depend as well on the softness of the rocks constituting the cliffs as on the violence of the seas. It would be to the western coasts of Ireland, Scotland, and some parts of England that one would naturally go for the best examples of the kind of work we are considering, for it is there that the rocks are exposed to the full fury of the Atlantic waves. At the same time, since, generally speaking, the rocks on the east coast are much softer than those of the western shore-line, the *rate* of erosion is there much greater than in the west counties. Some parts of the coast of Yorkshire and Lincolnshire are said to be worn away at the rate of three

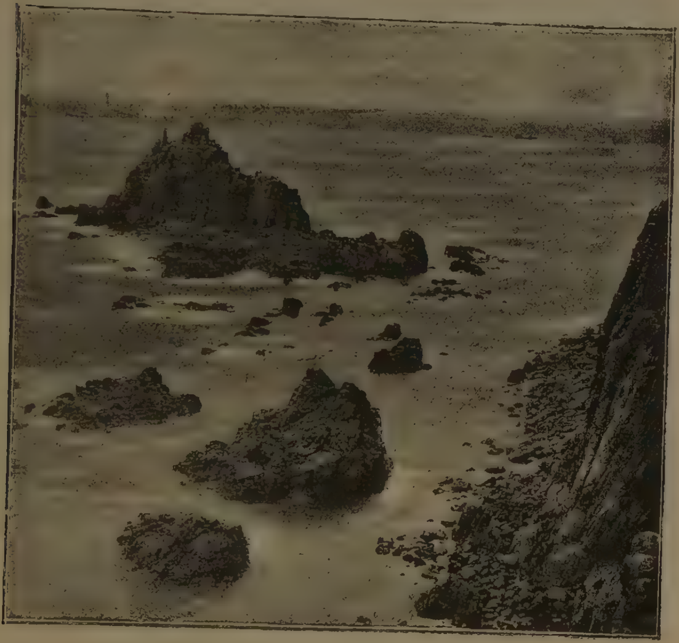

FIG. 112.—Sculpturing of the Land by the Ocean.

feet per year, while on the western coast there would not be this amount of erosion in a century. But the breakers themselves are often of sufficient force to wrench off huge masses without any aid from loose detritus. Many examples are on record, but it will be sufficient for our purpose to instance the case cited by Mr. Stevenson of the moving of a block weighing fifty tons by the waves at Barrahead in the Hebrides. The alternate compression and expansion of air in the crevices of rocks exposed to heavy breakers often dislocates heavy masses of stone far removed above the direct reach of the waves. The hydrostatic pressure of those portions of large waves which enter passages in the cliffs also acts in forcing off huge masses from the rocks.[1]

Deposition of Sediments.—The transporting power of a river depends upon its velocity. In estimating this velocity it must be borne in mind that it is the rate at which it overcomes the friction of its channel that is more particularly meant. A diminution of velocity will generally cause a deposition of suspended material.

When the velocity is still considerable after such a retardation has been experienced only the heaviest fragments will be thrown down. As the velocity is more and more diminished the lighter and lighter particles will sink to the bottom, until when the river loses itself in the quiet waters of a lake the whole amount of suspended matter will go to swell the deposit on its floor. A notable instance is found in the case of the Lake of Geneva, into which the rapidly moving Rhone empties its waters, and with them large quantities of suspended impurities. The muddy water of the Rhone can, from an elevated place, be traced far out into the lake, but the water which issues at the opposite end of the lake is beautifully clear and blue.

Such a diminution of velocity as we have described can be brought about in a great variety of ways.

1. By the passage of a river from the "mountain track" to the "valley track."

2. When a river overflows its banks as the result of a flood, which may be caused by excessive rainfall, or by a sudden melting of the snows near its source.

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[1] For a full and interesting account of the earth-sculpture effected by the agencies we have been able to do little more than mention, the student is urged to consult Sir A. Geikie's *Text-book of Geology*.

3. When a river enters the still waters of a lake, causing a deposition of material at the place where the stream enters the lake.

4. By rivers flowing into the sea, resulting in the formation of bars in some cases, or, as in the greater number of instances, of deltas, on a grander and larger scale than those formed in lakes. The manner of deposition, in the order of the specific gravities of the materials, has been already described on p. 252, while an account of the resulting deposits has been given in our introductory book.

Formation of Stratified Rocks.—It remains for us to see how the deposits thrown down in the manner just explained become hardened into the stratified rocks. There are two great causes at work bringing about this result, viz., the hardening of *pressure* and that brought about by *infiltration*. The student can easily convince himself of the effect of pressure in this direction by squeezing some mud under a heavy weight. The mud becomes drier and more compact as the weight is increased. It is not difficult to understand that the great mass of deposited sediment which is being continually added to will exert an enormous downward pressure upon the bottom layers, causing them in a similar manner to become desiccated and compact.

The process of infiltration can be imitated by pouring lime-water on to some sand contained in a glass, and then allowing the water to evaporate by placing it in a warm place. The lime which was dissolved in the water is deposited between the grains of sand, and binds them together in much the same way as in the mortar with which the mason binds the stones of a wall together. In nature, too, water containing such substances as lime in solution percolates into the mass of the deposit, and by its evaporation a layer of the dissolved material is thrown down which effectually cements the incoherent mass, converting it into a hard rock. Generally, both these agents, pressure and infiltration, work together towards the same result.

CHIEF POINTS OF CHAPTER XII.

Great Movements in the Earth's Crust.—*Secular movements* extend over great periods of time, and eventually result in a complete alteration in the contours of the land and water. *Continental elevations* may be thus brought about without any extensive fracturing or crumpling of the crust. Such uniformly elevated areas are often bounded by narrow rectilinear zones within which the strata have been tilted, folded, and compressed into colossal ridges.

Arrangements of Strata.—*Horizontal strata.*—Owing to their deposition in water in the order of their specific gravities it naturally follows that undisturbed strata are roughly parallel and horizontal. *Inclined strata* have been pushed up from the horizontal in consequence of movements in the earth's crust. In *inverted* strata this has resulted in the order of the beds becoming completely reversed.

Dip.—The angle which inclined strata make with the horizon is called the dip.

Outcrop.—The portion of an inclined stratum which is seen at the surface is called its outcrop. The width of the outcrop increases as the dip of the bed decreases.

Strike—The point of the compass towards which a line along the outcrop, at right angles to the dip, is directed is called its strike.

Folding of Strata.—Horizontal strata are often, as a result of great lateral pressures, brought about by movements in the earth's crust, thrown into folds. In *Anticlines* the strata dip away *from* the same line, in *Synclines* the strata dip *to* the same line. Folding may extend to the structure of individual rocks, when they are said to be *crumpled* or *contorted.*

Faulting of Strata.—When strata instead of continually bending actually fracture under an enormous tangential thrust, *faulting* is said to occur, and the break is called a *Fault.* The dip of the fault plane is called its *Hade.* The amount of movement of the strata when faulting occurs is known as its *Throw.* Faults may be *simple* or of the kinds known as *step-*, *trough-*, &c., faults.

Production of Mountain Structures.—(1) An exceedingly slow and enormously prolonged subsidence of that part of the earth's crust where the mountain chain will occur takes place. . This gives rise to a *Geosynclinal*, or very much thickened portion of the earth's crust. (2) Immensely powerful lateral or tangential thrusts throw the crust into huge folds, resulting in the formation of *Geanticlinals.* (3) Weathering and denuding agencies sculpture the range into its characteristic and picturesque forms.

Prof. Reyer maintains that such folding as referred to above does not depend on a contraction of our planet, as some authorities think, but is simply a gliding phenomenon.

Mountains due to other Causes.—Volcanic cones, hills of circumdenudation, table-lands of erosion are instances of these.

Types of Mountain Flexure.—The following are described—(1) Monoclinal flexures; (2) symmetrical flexures; (3) unsymmetrical flexures; (4) reversed flexures; (5) alpine type.

EARTH SCULPTURE.

Agents instrumental in Earth Sculpture.—The sculpturing action of *rain*, *rivers*, *glaciers*, *the ocean*, have all been described.

Rain is seen to be an active agent from its effects in the formation of *soils* and *subsoils*, *earth-pillars*, *grey wethers*, &c.

Rivers perform two kinds of work, viz., *chemical* and *mechanical*. The former results in formation of caves and the solution of many substances in river waters: the latter in the formation of *river-gorges*, *pot-holes*, and many other natural phenomena.

Glaciers.—The *moraines*, whether *lateral*, *median*, *ground*, or *terminal*, are all evidences of the activity of glaciers in transportation. The *roches moutonnées*, *striations*, &c., evidence their excavating power.

Oceans sculpture the coasts of all countries; where the rocks offer a great resistance we get rugged scenery, as on our own west coast—where the rocks are soft, as on many parts of the east seaboard, the land is being rapidly washed away.

Deposition of Denuded Material to form New Strata.—Whenever a diminution of the velocity of the water in which these materials are being carried takes place there is a deposition goes on, the heaviest fragments being thrown down first. Such a diminution of velocity can be brought about in many ways (p. 274).

Formation of Stratified Rocks.—Two great causes, *hardening by pressure* and *infiltration of cementing material*, are instrumental in the conversion of soft, damp sediments into hard, compact rocks.

QUESTIONS ON CHAPTER XII.

(1) What is meant by sub-aërial denudation, and what are the chief agents engaged in it?

(2) In what respects do rivers and glaciers resemble one another? State how they differ from one another in their mode of transport of materials from mountains to the sea.

(3) Compare the action of rain and rivers in producing the features of the earth's surface.

(4) How do you account for the fact that although stratified rocks were originally horizontal, or nearly so, they are rarely found horizontal now?

(5) Explain how the false bedding of strata has been produced.

(6) Describe briefly the generally accepted theory of the origin of mountain structure.

(7) What are the classes into which the patterns followed by mountain ridges may be divided?

(8) Give instances of the action of rain, rivers, and glaciers in changing the form of the earth's crust.

(9) Write a short essay upon the action of rivers upon the land surface near them.

(10) Compare rivers with glaciers as regards the part they play in earth sculpture.

(11) Describe some evidences of glacial action.

(12) Give an account of the work of the sea in wearing away a coast line.

(13) What causes may bring about a diminution or the rate of flow of a river, and what is the chief result of this diminution?

(14) Write a short essay upon the general mode of formation of stratified rocks.

CHAPTER XIII

THE UNIVERSE

CELESTIAL CO-ORDINATES, AND HOW THEY ARE AFFECTED BY THE EARTH'S MOVEMENTS

Determination of Positions upon the Sky.—We can define the position of any point upon the earth by stating its latitude and longitude; the latitude being angular distance, north and south, from the earth's equator, measured on a meridian; and the longitude the arc of the equator intercepted between the meridian passing through the selected point and some chosen meridian. Upon the celestial sphere the position of any point can be similarly expressed by two co-ordinates, but three systems of measurement instead of one are available, viz.:

(1) Altitude and Azimuth.
(2) Declination and Right Ascension.
(3) Celestial Latitude and Longitude.

Altitude and Azimuth.—The visible horizon may be roughly defined as the line along which the sky and earth appear to meet. In more precise terms the horizon of an observer is the great circle upon the heavens half way between the *zenith*, or the point exactly overhead, and the *nadir*, or the point under foot. Every circle which can be drawn through both the zenith and nadir is thus at right angles to the horizon. The celestial meridian (Fig. 113) is the vertical circle HZR, which passes through the north and south points; and the vertical circle WZE, the plane of which intersects the plane of the horizon at the east and west points, is termed the *prime vertical*. When any star or other celestial object is observed, the vertical circle upon which it lies is the circle drawn through it and the zenith. Let S in the accompanying diagram represent a star. Then the *altitude* of the star is the angular distance SOT from the horizon, measured on the vertical circle passing through the star. The complement of this, that is, the angular distance SOZ from the zenith, is the *zenith distance.* The *azimuth* is the arc of the horizon intercepted between the foot of the star's vertical circle and the south point of the horizon. If measurements are made from the east or west points the angular distance along the horizon is termed *amplitude.*

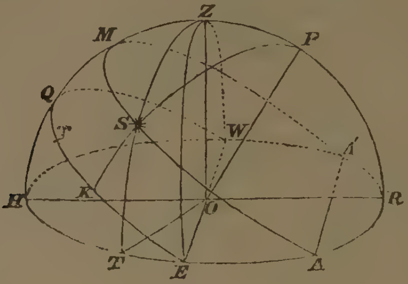


FIG. 113.—Sphere of Observation.

O, observer; *REHW*, horizon; *Z*, zenith; *S*, star; *AMA′*, parallel of star; *OP*, polar axis; *P*, north pole; *HZR*, meridian; *HR*, meridian line; *R*, north point; *H*, south point; *ZST*, vertical of star; *WZE*, prime vertical; *E*, east point; *W*, west point; *EQW*, equator; *PSK*, declination circle of star; ϒ, "First point of Aries."

ST, altitude; *SZ*, zenith distance; *HT*, azimuth; *SK*, declination; *rK*, right ascension.

Measurement of Altitude and Azimuth.—From the foregoing it will be understood that the position of a celestial object at any instant may be defined by the altitude and azimuth system of co-ordinates. An instrument by means of which these co-ordinates may be measured is shown in Fig. 114. By means of spirit levels and the screws at its base the instrument can be set horizontally. The telescope moves in a vertical plane round the vertical circle in the illustration. Attached to it are two small portions of a divided circle which, when the telescope moves, slide round the fixed vertical circle and so serve as pointers. The angle which the telescope makes with the horizontal can be read off in degrees, minutes, seconds, on the vertical graduated circle, and measures the altitude of the object

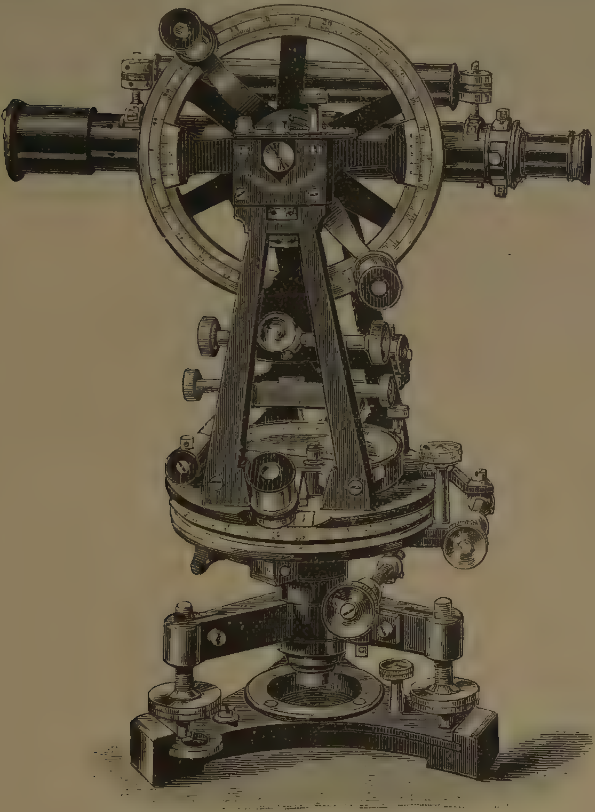


FIG. 114.—The Theodolite, or measuring Altitude and Azimuth. (The type of instrument made by Louis P. Casella.)

which is being viewed by the telescope. The telescope being now clamped in position, it is possible to move the whole framework supporting it round in a horizontal plane, and the angle through which it must thus be moved from the south point measures the azimuth.

It should be mentioned that in the case of bodies which are moving across the sky there is a constant change of altitude and azimuth.

Declination and Right Ascension.—The celestial poles may be regarded either as the points in the celestial sphere directly above the poles of the earth, or as the points where the earth's axis produced meets the celestial sphere. The celestial equator is a line drawn round the sphere half-way between the poles. Circles passing through both poles thus cut the celestial equator at right angles.

The celestial co-ordinate termed *Declination*, is analogous to terrestrial latitude, being roughly defined as angular distance north and south of the celestial equator. More exactly, the *Declination of a heavenly body is its angular distance from the equator measured along a circle passing through the body and the celestial poles.*

Imagine two luminous circles traced upon the heavens, one directly above the earth's equator, and the other marking the place where the plane of the earth's orbit intersects the celestial sphere. These circles would represent the celestial equator and the ecliptic. They would cross one another at two points, and their greatest angular distance apart would be 23°·27′. Many years ago one of these points was situated in the constellation of Aries, and the other in the constellation Libra in the opposite part of the sky. On March 21 in each year the sun is directly in front of the point of intersection near the constellation of Aries, and known as "the first point of Aries." This is the point from which *Right Ascensions* are reckoned, just as terrestrial longitudes are measured from Greenwich. In more precise terms, *Right ascension is the angle which a celestial meridian passing through the centre of a celestial body makes with that which passes through the first point of Aries, that is, the point occupied by the sun at the vernal equinox.* Right ascensions are generally reckoned from 0 hours to 24 hours of sidereal time from west to east, that is to say, in the opposite direction to the apparent diurnal movement of the heavens (Fig. 115).

Celestial Latitude and Longitude.—It is unfortunate that these terms are *not* reserved for the celestial co-ordinates declination and right ascension, which are exactly analogous to our latitudes and longitudes. The plane of the ecliptic is the standard of reference; and the latitude of a star is its angular distance from the ecliptic, while the celestial longitude is angular distance from the first point of Aries, measured along the ecliptic, instead of the equator, from 0° to 360°.

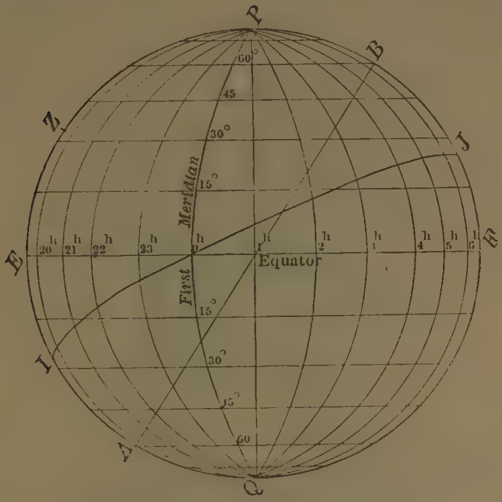


FIG. 115.—Circles of the Celestial Sphere.

AB, horizon; *Z*, zenith; *PQ*, celestial poles; *EF*, celestial equator. The first meridian is the line from which right ascensions are reckoned in hours, minutes and seconds, in the manner shown. Parallels of declination are indicated upon this line. *IJ* is the ecliptic.

Measurements of Declination and Right Ascension.—It has been pointed out that right ascension is usually counted in sidereal hours, minutes and seconds eastward along the celestial equator. Returning to our illustration of two luminous circles traced upon the heavens, we may regard the circle representing the celestial equator as divided into twenty-four parts and numbered from 0 to 24, the first point of Aries being the starting-point. When, therefore, we know the interval in sidereal hours, minutes, and seconds between the first point of Aries and a celestial object we know the object's right ascension. To determine this interval we need (1) a transit instrument, and (2) a clock keeping sidereal time.

The transit instrument is adjusted so that it always lies in the plane of the meridian. It consists of an astronomical telescope, which is firmly fixed at right angles to a horizontal plane between two vertical uprights, and supported so that it can move up or down in a vertical plane (Fig. 116). The eyepiece of the telescope is provided with cross-wires, several vertical, and one or two horizontal. When the telescope is moved up or down, the central vertical cross-wire traces out a line which passes through a point exactly overhead, called the *zenith*, and also, for the instrument is so fixed, through the north and south points on the horizon. The line thus traced out is, of course, the meridian. When, therefore, the image of a star crosses the vertical cross-wire of such an instrument, or *transits*, as it is

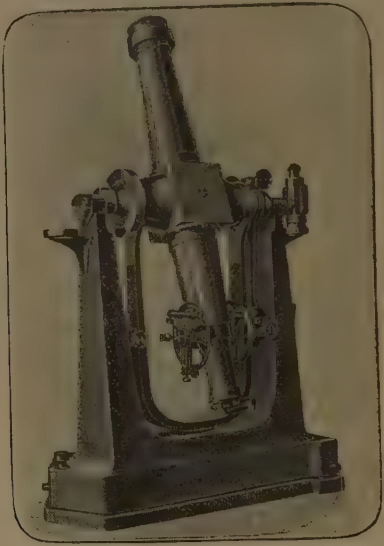


FIG. 116.—Cooke's Form of Transit Instrument.

called, we have the exact second of the star's southing. The interval between such an observation and a similar one with the same star the next night is an exact sidereal day.

The astronomical clock is regulated so that it always indicates 0h., 0m., 0s., when the first point of Aries is on the meridian. As the heavens are carried round in their apparent diurnal motion the sidereal clock keeps time with it, and in a complete rotation the clock runs through 24 sidereal hours. The time indicated by the astronomical clock thus shows how the heavens are passing; and remembering what has already been said, it will be easy to understand that the *right ascension of an object is the time indicated by an astronomical clock when the object transits.* The exact time of transit is found by observing the time at which the star or other object appears upon each of the vertical wires (Fig. 117), (which represents the field of view of a transit instrument), and then taking the mean of the observations, which gives the time of transit over the middle wire.

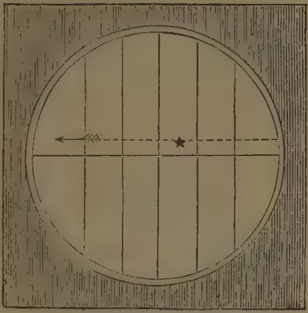


FIG. 117.—Spider lines in the field of view of a Transit Instrument. The middle vertical line marks the meridian. The direction of motion is that seen with an inverting telescope.

The declination of a star is also measured by means of the transit instrument or a similar meridian instrument. Graduated circles attached to the telescope enable the inclination of the telescope to be determined. If the inclination of the telescope is observed when an object is in the centre of the field of view, the difference between this reading and that shown when the telescope is pointed to the celestial equator is the declination of the object. Usually the declination is found by observing the zenith distance of the object in transit. Then, knowing the latitude of the place of observation, the object's north declination is given by the equation:—

$$\begin{array}{c}\text{North}\\ \text{declination}\end{array} = \begin{array}{c}\text{latitude}\\ \text{of observatory}\end{array} + \begin{array}{c}\text{the meridian}\\ \text{zenith distance.}\end{array}$$

THE EARTH'S MOVEMENTS.

Methods of Determining the Rotation of the Earth.—The elementary facts in connection with the earth's rotation are, it will be assumed, well known to the student, and it will be sufficient for us here to describe two of the methods which are adopted for the experimental demonstration of this spinning movement. The first of these is by means of Foucault's pendulum.

Foucault's Pendulum.—Newton's first law of motion asserts that all matter possesses inertia. Foucault made use of the possession of this property by a heavy pendulum to demonstrate the earth's rotation. If such a pendulum be set oscillating it resists any attempt to force it out of the plane in which it is swinging. The device shown in Fig. 118, due to Mr. R A Gregory,[1] shows this very prettily.

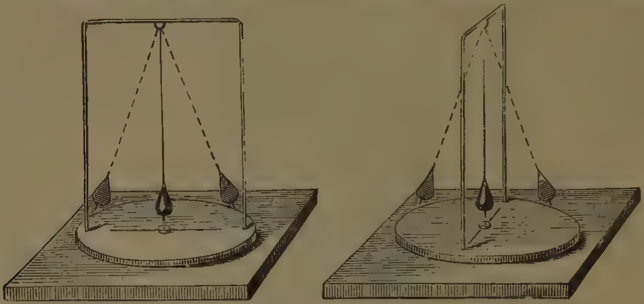


FIG. 118.—Model to show that the fine wire suspending a vibrating weight can be twisted without changing the direction of vibration.

EXPT. 31.—Swing a heavy ball suspended freely by a wire from a point fixed to a support which rests on a board that can be moved round as required. Let a hog bristle just touch the board, and on the board place a smooth piece of paper covered with lamp-black. Cause the pendulum to swing, by moving it to an angle with the vertical by a piece of thread and then cutting the thread with scissors. Slowly rotate the board round a centre. It will be found that the ball swings in the same direction as regards the room as that in which it originally started, and regardless of the motion of the board.

[1] *The Planet Earth.*

Making use of this fact, Foucault suspended a heavy iron ball by means of a long thin wire from the roof of the Panthéon in Paris. The pendulum thus formed was pulled out of the perpendicular and held on one side by a thread which was attached to the wall. Foucault caused the pendulum to swing to and fro over a circle of sand on the floor of the Panthéon, but the experiment can be as satisfactorily done if a table, on which marks have been drawn, be substituted.

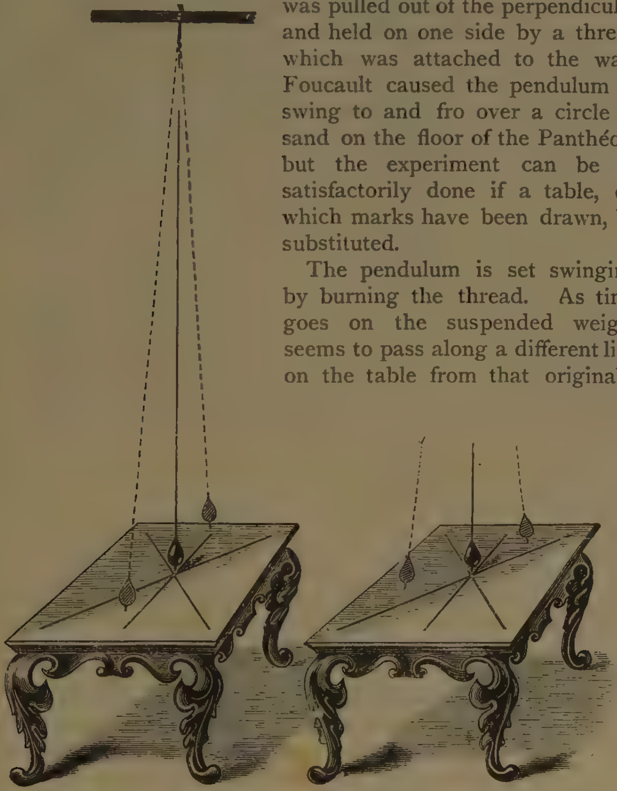


Fig. 119.—Experiment with Foucault's Pendulum. The left-hand figure shows the pendulum started over a central line drawn upon a table; the right-hand figure shows the apparent charge after about two hours vibration at a place in the northern hemisphere

The pendulum is set swinging by burning the thread. As time goes on the suspended weight seems to pass along a different line on the table from that originally traversed and, it is clear that one of two things must have happened—either the plane of the pendulum's oscillation must have altered, or else the table must have turned round. But the experiment we have described shows that the former alternative is an impossible one, and we are forced to the conclusion that the table, and therefore the earth of which it is a part, gradually turns round. If this experiment were performed at either of the poles (Fig. 120), the pendulum plane, as shown by the movement of the table, would (neglecting friction) move through 360° in a day; at the equator, it would not turn at all (Fig. 121); and in intermediate latitudes the movement varies according to the latitude.

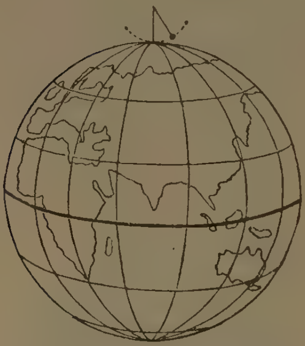


FIG. 120.—Motion of a Foucault's pendulum suspended at the north pole. The plane of oscillation would gradually shift from east to west.

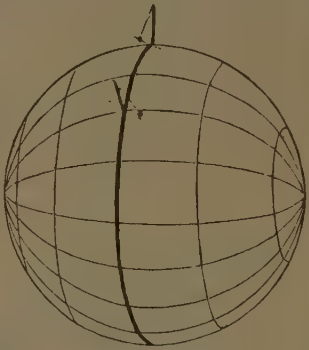


FIG. 121.—Motion of a Foucault's Pendulum suspended at the equator. The plane of oscillation would not change.

The plane of oscillation of the pendulum appears slowly to move from east to west on account of the earth's rotation from west to east. In the northern hemisphere, therefore, the plane of oscillation seems to rotate in the same direction as that in which the hands of a watch move, and in the southern hemisphere the bias is anti-clockwise.

Foucault's Gyroscope.—The gyroscope was a later device of Foucault's for demonstrating the rotation of the earth. The method is not so satisfactory as the pendulum plan, though the principle involved is identical. A heavy wheel is made to rotate at a high velocity by means of a suitable multiplying apparatus, and while thus spinning is removed and placed in position on the gyroscope. When in position the rotating wheel is supported on knife edges, which rest on true planes by means of an arm which is suspended at right angles to a circular piece of metal, as shown in Fig. 122. The wheel rapidly revolving in the same plane as this piece of metal gives it a rigidity in that direction, so that any force acting at an angle to it has no effect; consequently, a pointer rigidly fixed to this piece of metal will remain perfectly still, whilst the earth will rotate under the gyroscope and carry a scale, the instrument, and the table on which they are placed, with it.

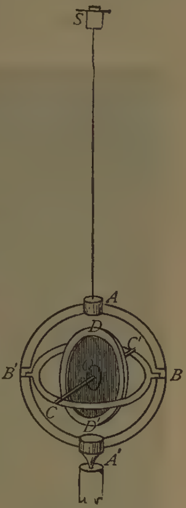


FIG. 122.—Foucault's Gyroscope.

DD′ heavy metallic disc, with axis supported in pivots *CC′*. *BCB′C′*, circular ring supported horizontally at *B′B*. *ABA′B′*, vertical circle suspended by a fine wire *SA* from the fixed point *S*. *A′*, pivot resting in a small hole. The disc *DD′* is rapidly rotated, and it retains its plane of rotation while the other parts of the instrument are carried round with the earth.

Apparent Movements of the Stars due to the Earth's Rotation.—We must now consider the changes which are noticed in the apparent movements of the stars as we move either from the equator to the poles or in a contrary direction. These movements are, as has been seen, the outcome of the earth's rotation.

1. When the observer is at either of the poles, say the north, the pole-star appears exactly overhead: indeed, it is so named because if the earth's axis were continued to meet the heavens, it would pass almost exactly through this star. The horizon is contained by the plane passing through the earth's equator, that is, the *celestial equator* and the horizon coincide. All stars appear to move round the observer in circles, and remain visible throughout their diurnal journey. Or we may say their apparent paths are always parallel to the horizon.

2. When the observer is at the equator the pole-star appears on the horizon, and all the stars seem to describe semicircles in the heavens. The planes containing the paths of the stars are

all vertical, and consequently stars on the celestial equator, when in their highest positions, will be exactly in the zenith.

3. When the observer is in middle latitudes, say at London, the stars seem to belong to three classes: (1) Those which can

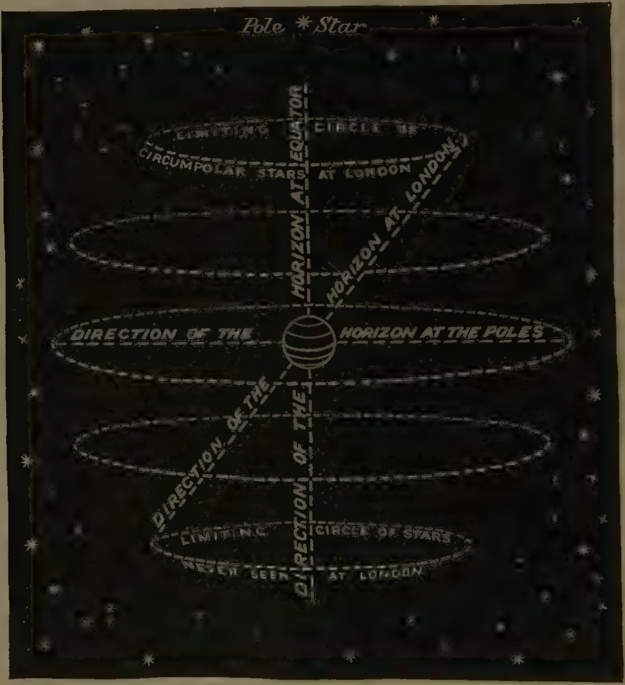


Fig. 123.—To explain (1) why the altitude of the pole star varies with latitude, (2) the apparent paths described by stars when viewed at the poles, at London, and at the equator.

be seen throughout the whole of their apparent journey, *i.e.*, which never set; (2) those which are visible only for a part of their apparent path, *i.e.*, which both rise and set; (3) those which never come into sight at any period of their apparent diurnal motion, *i.e.*, which never rise.

Apparent Motions of Stars around the Celestial Poles.—If the northern sky be watched on a fine night all the stars will be seen to turn as if they were fixed on a solid vault pivoted at a point near the north star, or pole-star. A striking way to show this is afforded by photography.

EXPT. 32.—Point a lens and camera, containing a sensitive plate, to the pole-star, and expose it for a couple of hours. Then take out the plate and develop it.

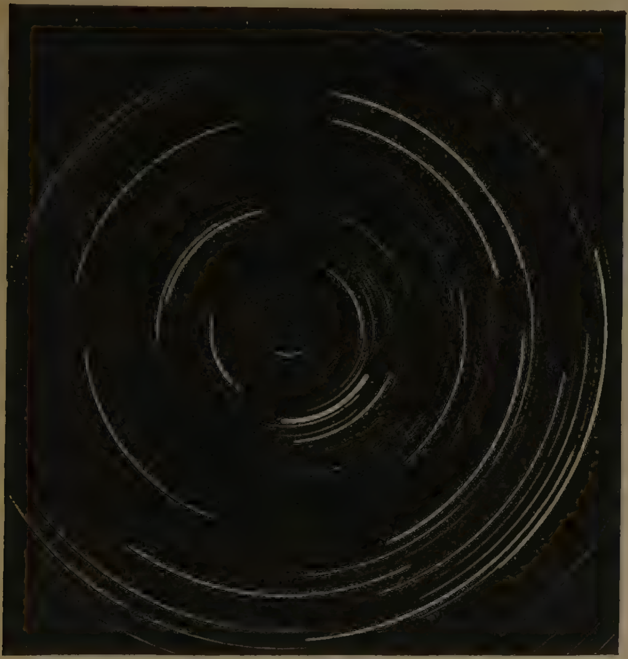
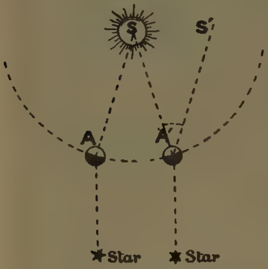


FIG. 124.—Photograph of the apparent Rotation of Stars around the North Celestial Poles in two hours fifty minutes. The bright Arc about three-quarters of an inch below the centre represents the trail of the Pole Star, which is 1° 15′ away from the pole.

While the camera is directed towards the sky the stars apparently move around the north celestial pole, the result being that they all leave trails upon the photographic plate (Fig. 124). The pole-star will trace an arc of a very small circle (thus proving that it is not situated absolutely at the pole), while the other trails will be arcs of much larger circles. A similar result is obtained if a photograph is taken of the region around the south celestial pole by a photographer in the southern hemisphere. This indicates that the earth is in rotation, the north and south celestial poles being the points above the ends of the axis of rotation.

Apparent Daily Motion of a Star.—Just as in the case of the sun, so we have seen with all the stars, they rise, *south*, and set. But whereas with the sun the interval between two successive southings varies throughout the year, it is found that the time which elapses between two succeeding southings of a star at any season of the year is always the same. This interval constitutes *a star*—or *sidereal-day*. If, then, we can find some means of ascertaining the exact moment at which a star souths or passes over the meridian of a place, we have a method of measuring time in terms of an interval of time which is always the same.



IG. 125.—To show the difference between Solar and Sidereal days. Observations of the transit of a star give the exact time of the earth's rotation. If, however, the transit of the sun is observed from A, then when the earth gets to A′, it has to turn through the angle SA′S′, in addition to a complete rotation, before the sun transits again.

The Time of Rotation of the Earth is easily determined by means of the transit instrument, for it is evident that the interval between two successive transits of a star, or as it is called, a sidereal day, is the time of such rotation. The sidereal day is 23 hours 56 minutes 4 seconds of mean time, or 3 minutes 56 seconds shorter than a mean solar day. No matter what star is selected for observation the interval is the same, thus showing that the earth is rigid and that all parts of its surface have the same angular velocity. The sun is not employed in determining the time of rotation, because on account of the earth's revolution it appears projected upon a different part of the sky day after day, instead of occupying a fixed position, as is the case with a star. The result is that the interval between two successive transits of the sun's centre over a given meridian is not constant (Fig. 125).

The Revolution of the Earth.—The earth, in addition to its regular rotation upon its axis, has another motion which carries it round the sun on a fixed path called its *orbit*, once in a year. Attention has already been called to the universal law of gravitation as enunciated by Newton, which expresses the fact that every mass attracts every other with a force varying as the product of their masses and inversely as the square of the distance between their centres. In addition to this it has been seen that the inertia possessed by all moving matter gives it a tendency to continue its motion in a straight line. The sun is 330,000 times heavier than the earth; and had we only the first of the above laws to govern the earth's movement in space, it is manifest that the earth would be attracted with so great a force by the sun that it would be drawn in towards it and would become part of the sun. But there is at the same time the tendency which the earth possesses to move off in a straight line into space. The earth's orbit represents, therefore, the resultant of these two forces, which are continually acting upon it. It is for these reasons, too, that the earth moves round the sun, and not the sun round the earth.

The Sun's Apparent Motion caused by the Earth's Revolution.—On account of the earth's change of position as it travels round its orbit, the stars appear in slightly different positions with reference to the sun when watched from month to month. The condition of things is exactly analogous to that in the case of a cyclist carreering round a racing track in the centre of which we may suppose an electric light to be situated. Distant objects will appear in different directions with reference to the light, when observed by him from different points of the course.

In the same way the earth travels round the sun, and, as a consequence, the sun appears to be projected upon different star-groups at different times of the year. As the earth's track is a plane, the level of which is practically constant from year to year, the sun's apparent path through the stars undergoes no change as the years roll on. This path is termed *the ecliptic*, and it is evidently the line of intersection of the plane of the earth's orbit with the celestial sphere. In exact words, we may define the ecliptic as *the trajectory marked out by the sun in its apparent motion among the stars.*

The plane of the earth's orbit furnishes us with a plane of reference (p. 283) for astronomical measurements; the plane of the earth's equator provides us with another. The celestial equator is the intersection of the plane of the earth's equator, if produced, with the celestial sphere; it is the circle of the heavens lying exactly overhead to an observer at the earth's equator. The inclination of the two planes—that of the ecliptic and that of the equator—is at the present time $23^\circ{\cdot}27'$. This inclination, termed the *obliquity of the ecliptic*, diminishes by about $0''{\cdot}46$ per annum.

The apparent motion of the sun among the stars would seem at first sight to be sufficiently strong evidence that the earth revolves in an orbit, but it is not an unassailable proof; for, if the sun actually revolved round the earth, the same appearances would be produced. The proof is furnished by a minute effect known as the aberration of light, which the earth's revolution produces upon the apparent positions of the stars.

Aberration Effects.—*A Railway Journey in a Shower of Rain.*—The meaning of aberration is most easily grasped by the consideration of some familiar examples of its effects. The reader has doubtless at some time found himself in a railway carriage at rest during a shower of rain, and has noticed that the paths of the drops under such circumstances are vertical. But, as the train begins to move, the drops appear to fall in a slanting direction. Moreover, if the train moves with an increasing velocity, the apparent slant of the drop becomes greater.

Suppose we try to arrange a tube to catch the drops in such a way that they move to the bottom of the tube without touching the sides. It is manifest that when the train is at rest we shall have to hold the tube vertically; and, after the train has begun to move, *the tube will have to be tilted more and more towards the point in which the train is moving as its speed is increased.*

Shots fired from a Battery.—The case of shots being fired from a fort at a ship out at sea is another good example of the same principle. If a shot strikes a ship at rest, the hole at which the shot enters and that at which it leaves the ship are in one and the same straight line with the longer axis of the gun. If, however, the ship is moving in a direction at right angles to the length of the gun, the hole at which the shot leaves the ship will not bear the same relation to that where it enters which it did before. During the time which it takes the shot to pass over the breadth of the ship, the ship itself has travelled a certain distance, and the point of emergence will appear to be at some distance astern of the place where it entered, the amount of this divergence depending upon the velocity of the boat. Fig. 126 makes this quite clear. An observer situated upon the moving ship would think the shot came from a battery opposite *b* instead of opposite B, that is, in advance of the real position, if he did not take the velocity of the ship into consideration.

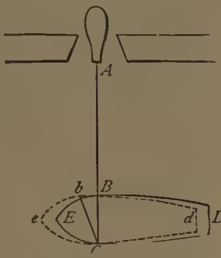


FIG. 126.—To illustrate the effect of Motion in altering apparent position.

Aberration of Light.—It was found by Bradley in 1726 that certain stars undergo minute changes of position in the course of a year, and that these variations recur annually. If the average of all the observations of a star during the year is taken as the true place of the star upon the celestial sphere, then it is found that the observed position of the star on any night differs slightly from the mean position. *The apparent displacement from the mean position is always towards that point of the heavens to which the earth is moving at the moment of observation.* For simplicity, consider a star situated at the pole of the ecliptic, and the earth in four different

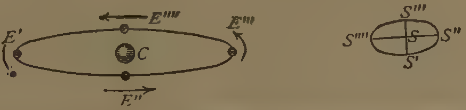


FIG. 127.—E', E'', E''', E'''', positions of the Earth in its Orbit; S', S'', S''', S'''', corresponding displacements of the Star S.

positions in its orbit (Fig. 127). The centre of the small ellipse may be regarded as the true place of the star. When the earth is at E′, and moving in the direction shown, the star is observed at S′, and, similarly, when the earth is at E″, E‴, E⁗, the star is displaced to S″, S‴, S⁗, the displacement in each case being 20″·5 in advance of the star's true position. This displacement (20″·5) is the same for all stars, and is known as the constant of aberration. In the case of a star at the pole of the ecliptic, a circle 20″·5 in radius appears to be described around the pole of the ecliptic annually. A star on the ecliptic appears to oscillate 20″·5 east and west of its mean position in a yearly period. Every star between the ecliptic and the ecliptic poles appears to describe a minute ellipse, the semi-major axis of which is 20″·5, while the minor axis varies with the latitude of the star. As an illustration of the minuteness of aberration effects, it may be pointed out that the angular diameter of the full moon is about 31′, so that the constant of aberration is about $\frac{1}{90\text{th}}$ of the apparent distance from one edge of moon to the other (for $\frac{31'{\cdot}0''}{20''{\cdot}5} = 90$).

Proof of the Revolution of the Earth.—The aberration of light furnishes a conclusive proof of the revolution of the earth around the sun. If the earth were at rest, and the earth's atmosphere did not exist (in which case there would be no refraction), every star would be seen in its true direction. But, since this condition of things does not hold, the earth must be in motion, and, as we shall see more fully later, it moves in an orbit at a mean distance of 93,000,000 miles from the sun.

In a year the earth travels once round its orbit, which we may at first consider as approximately circular; and since the length of the circumference of a circle is equal to twice its radius multiplied by the fraction $\frac{22}{7}$, as we have before seen, we can find the number of miles travelled by the earth in a year by the following expression:

Miles travelled by the earth in a year $= 2 \times 93{,}000{,}000 \times \frac{22}{7}$

which is equal to 18·2 miles in one second. Now the velocity of light (p. 69) is about 186,000 miles per second, and if in

Fig. 128 the light from the sun is supposed to travel along the direction SE, and at the beginning of any one second the earth be in the position E, at the expiration of that interval the earth will be at E′. Then the distance SE will represent the space traversed by light during the time that the earth travels from E to E′, and the angle ESE, will represent the amount of aberration due to the relative velocities of light, and of the earth on its orbit. Moreover, in trigonometry, the ratio between the sides EE′ and ES, that is the perpendicular side, and the base of a right-angled triangle, which we may, for so small an angle, consider our triangle to be, is called the *tangent* of the angle ESE′, or

$$\frac{EE'}{ES} = \text{tangent } ESE'$$

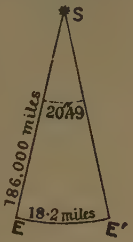


FIG. 128.—To illustrate the relation between the velocity of light and the Earth's orbital velocity.

$$i.e. \ \frac{\text{Velocity of earth}}{\text{Velocity of light}} = \text{tangent of angle of aberration}$$
$$= \text{tangent } 20''\cdot 49.$$

Apparent Annual Variation of Sun's Diameter.—Measurements show that the sun's angular diameter decreases from January 1 to July 2, and then increases again to the next January 1. We know that the further a body is taken away from an observer the smaller it appears to be, the diminution, moreover, being proportional to the distance between the observer and the object. We are thus driven to the conclusion that the earth is further from the sun in July than in January: for if the distance remained constant, the apparent angular diameter of the earth would be the same at all seasons of the year. On January 1 the angular diameter of the sun is 32′35″·76, while on July 2 it is only 31′28″·94. (See p. 325.)

Shape of the Earth's Orbit. — The facts which the student has now learnt, viz., that the distance of the earth from the sun is not constant, but varies regularly from month to month, and that the earth revolves round the sun once in a year, force us to the conclusion that the shape of the path on which it travels round the sun is what is known as an ellipse, for this is the only closed curve which admits of these relations between the two moving bodies. Such a curve is shown in

Fig. 129, in which the line A A′ is called the *major axis*, and B B′ the *minor axis*. The points S S′ are called the *foci* of the ellipse, and are located by describing arcs with B as centre, and A O, or a half the major axis, as radius. The sun occupies

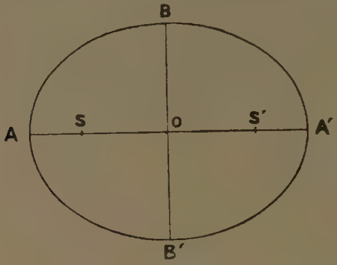


FIG. 129.—To illustrate eccentricity of an Elliptic Orbit.

the position of one focus S. In an ellipse the ratio between the distance from its centre O and one focus S to half the major axis is called its eccentricity, or,

$$\frac{\text{O S}}{\text{O A}} = \text{eccentricity of the ellipse} = e.$$

The distance A S, that is, the distance between the earth and the sun when they are nearest together, is called the *perihelion distance*, for under these circumstances the earth is in *perihelion*. Similarly, when the earth is at A′, it is in *aphelion*, and the distance A′ S is the *aphelion distance*.

$$\begin{aligned}\text{Aphelion distance A}' \text{ S} &= \text{A}' \text{ O} + \text{O S}\\ \text{A}' \text{ S} &= \text{A}' \text{ O} + e.\text{A}' \text{ O} \quad (\text{from def. of } e)\\ &= \text{A}' \text{ O } (1+e).\end{aligned}$$

$$\begin{aligned}\text{Similarly perihelion distance A S} &= \text{A O} - \text{O S}\\ \text{A S} &= \text{A}' \text{ O} - e.\text{A}' \text{ O}\\ &= \text{A}' \text{ O } (1 - e).\end{aligned}$$

$$\frac{\text{Aphelion distance}}{\text{Perihelion distance}} = \frac{1+e}{1-e}$$

Let aphelion distance $= \text{A}$
and perihelion distance $= \text{P}$

Then $A+P=$ twice semi axis major . . . . . . $= 2\,AO$
and $A-P=$ twice distance between the centre
of the ellipse and its focus . . . $= 2\,OS$

But by definition of eccentricity :—

$$\frac{OS}{OA} = e$$

$$\therefore \frac{A-P}{A+P} = e$$

From which, dividing through by A, we get, $\dfrac{1-\frac{P}{A}}{1+\frac{P}{A}} = e$

But we have seen that the perihelion distance and the aphelion distance are in the inverse ratio of the apparent angular diameters of the sun at these times, or $\frac{P}{A}$ (for the earth's orbit) $= \dfrac{31'\ 30''\cdot 2}{32'\ 34''\cdot 6} = \cdot 96705$.

It is easy by substituting this value for $\frac{P}{A}$ in the above equation for e to deduce the eccentricity of the earth's orbit. It will be found to work out to 0·0168, but its value is slowly diminishing year by year.

Precession and Methods of Determining it.—Accurate measurements are continually being made of the positions of stars upon the celestial sphere. But the positions which the stars appear to have are not those which they actually do occupy ; for refraction, aberration, and other causes have each an effect upon the measures obtained by astronomers. It is possible, however, to take these disturbing influences into account, and, when their effects have been eliminated, to obtain a catalogue of the celestial co-ordinates termed *declinations* and *right ascensions*, of stars. A comparison of two such catalogues obtained in different years, extending over as long an interval as possible, would prove that though the latitudes of the stars were very nearly the same in the two cases, the longitudes would all show an increase at the rate of 50″·2 per annum. Now celestial latitudes are reckoned from the plane of the ecliptic, and the fact that they are practically constant year after year indicates that the ecliptic is very nearly a fixed plane in space. With regard to the celestial longitudes, however, the general increase shown by the comparison of sets of measures of star-places made after an interval of some years, indicates that the reference point moves. The effect is similar to what would be produced if Greenwich Observatory, from the meridian of which we count terrestrial longitude, were to gradually slide westwards from its present position. Now celestial longitudes are reckoned from the meridian which passes through one of the points where the ecliptic and celestial equator cross one another. The conclusion is, therefore, that this point—the first point of Aries—is gliding backwards along the ecliptic at the rate of 50″·2 per annum, and, as a result, the longitudes of stars are apparently increased at the same rate. The right ascensions of stars are also reckoned from the first point of Aries, so they are subject to the same general variation as the longitudes. It is this apparent increase in the longitude and right ascension of stars which is referred to under the heading *precession*.

Illustration of Effects of Precession.—The ecliptic plane may for the present be regarded as fixed, and the angle ($23\frac{1}{2}^{\circ}$) which the plane of the earth's equator makes with it varies but very little. But, as has been explained, the points where the two planes intersect are in motion, and this result can only be produced by a change in direction of the plane of the equator. The nature of this motion can be made clear by an experimental illustration.

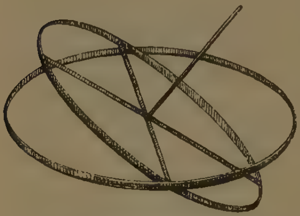


FIG. 130.—Experiment to illustrate inclination of an Orbit to the Ecliptic Plane, and the effects of precession.

EXPT. 33.—Procure two wooden hoops about two or three feet in diameter. Fix one horizontally to represent the ecliptic. Nail two laths on the other hoop at right angles to one another, so that they cross at the centre, and at the place where they intersect fix a thin rod at right angles to them. Place this hoop inside the other one so that the angle between the two is about $23\frac{1}{2}^{\circ}$. The hoops may thus be used to illustrate the ecliptic and equator (Fig. 130).

Evidently, if the hoops remain in one position, the position of fixed objects in the room are constant with reference to them. But if the inclined hoop be moved so that, while the inclination remains the same, the direction of the laths is altered, certain differences will appear. The positions of objects above and below the horizontal fixed hoop would not be affected. This is analogous to the constant latitudes of stars. The change in the direction of the intersecting line of the two hoops is similar to that which causes the longitude and right ascensions of stars to

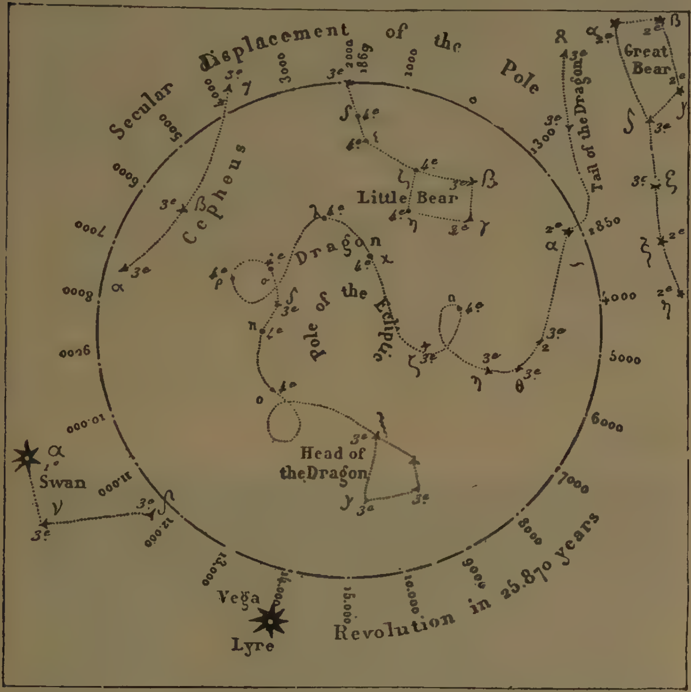


FIG. 131.—The precessional revolution of the North Celestial Pole around the North Pole of the Ecliptic. It will be noticed that different stars are "Pole-Stars" at different epochs.

vary. Another variation which can be imitated by the model is that of the declinations of stars. If the inclined hoop be moved around the horizontal one, evidently the positions of objects with reference to its plane are altered. In a similar manner, the declinations of stars, being reckoned above and below the plane of the equator, are altered by the movement of that plane, the maximum change being 47°, that is, twice the obliquity of the ecliptic. The light rod on the laths points out the pole; it represents the direction of the earth's axis. As the inclined hoop is moved the rod is seen to point o different parts of the ceiling of the room, and if the line of intersection of the hoops is moved completely round the horizontal hoop, the end of the rod will describe a small circle, just as the poles of the earth, and, therefore of the heavens, appear to describe circles around the poles of the ecliptic in about 25,800 years (Fig. 131).

The Cause of Precession.—If the earth were a sphere and uniform in structure, there would be no precessional effects.

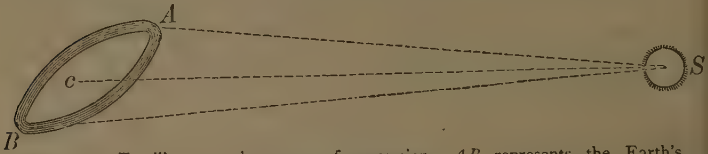


FIG. 132.—To illustrate the cause of precession. *AB* represents the Earth's equatorial protuberance revolving round the Sun *S*. *c* represents the centre of the Earth. The attraction of the Sun upon *A* is greater than at *c*, and the attraction at *B* is less than at *c*. The tendency is therefore for the ring to be pulled into the line *Sc*, but as the Earth is rotating, the motion of precession is produced.

The steady shifting of the plane of the equator is produced by the differential attraction of the sun and moon upon the matter by which the figure of the earth is in excess of the spherical shape. This protuberance forms a belt around the equatorial regions of the earth, and the tendency of the lunar and solar attraction is to pull it into the plane of the ecliptic (Fig. 132). The rotation of the earth prevents this result from being obtained; and, instead of the two planes being made to coincide, the direction of the plane of the equator shifts in the manner already described. The line of equinoxes, which is formed by the intersection of the planes of the equator and ecliptic, is, therefore, constantly moving. The motion is retrograde, that is, opposite to the direction of the earth's revolution in its orbit, and the rate of this precession of the equinoxes is 50″·2 per annum. To travel completely around the ecliptic at this rate takes about 25,800 years $\left(\frac{360^\circ\ 0'\ 0''}{50''\cdot2} = 25{,}800\right)$.

A spinning top furnishes a familiar example of motion similar to precession (Fig. 133).

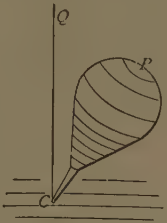


FIG. 133.—*CP*, axis of spinning top; *CQ*, vertical line. When the top is spinning, it does not fall from the position shown, but *CP* rotates round *CQ* in the same direction as the direction of rotation. (From Airy's *Astronomy*.)

Nutation and Methods of Determining it.—When accurate measurements of the declinations of stars are examined after all the effects of disturbing influences have been eliminated, they are found to show an increase for about 9 years, followed by a decrease for the same period, the greatest change of declination being rather less than 18″. The precession of the equinoxes also varies in the same period, viz., 18 years 7 months, moving in some years more than 50″·2, and in other years less. The conclusion from such observations is that the poles of the equator do not describe true circles around the poles of the ecliptic, but trace out wavy lines upon the celestial sphere, being sometimes nearer and sometimes further from the ecliptic

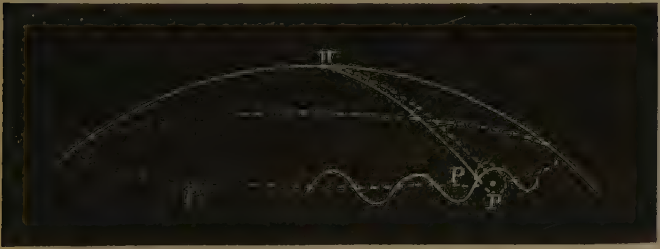


FIG. 134.—To illustrate Nutation. π, the Pole of the Ecliptic. The precessional motion of a Celestial Pole round the Pole of the Ecliptic is shown by the dotted line, the small dotted Ellipse PP shows the nutation effect, and the wavy line the movement of the Pole in consequence of nutation and precession.

poles. This change signifies that the plane of the equator swings very slightly up and down, as it turns around the plane of the ecliptic, and, in consequence of the movement, the declination of stars are slightly affected. If there were no precession, each of the poles of the heavens would describe a minute ellipse—only 18″ long in its major axis—in 18 years 7 months. But, on account of precession, the celestial poles are carried round the poles of the ecliptic in 25,800 years, and the small secondary nodding or *nutation* of the earth's axis is superposed upon it. Thus the true path of the pole of the heavens around the pole of the ecliptic is a wavy line (Fig. 134). *Nutation is, indeed, a minor periodic variation of precession.*

Cause and Effects of Nutation.—It has been pointed out that precession is caused by the attraction of the sun and moon tending to pull the equatorial protuberance of the earth into the plane of the ecliptic. This tendency must evidently vary according to the relative positions of the sun and moon with reference to the plane of the equator. At the equinoxes the sun is on the equator, consequently its influence in producing precession is then zero, whilst at the solstices the sun's action in tending to pull the equator into the ecliptic is greatest. In like manner, the influence of the moon vanishes twice a month, viz., when our satellite is at the nodes of its orbit; and a maximum effect is produced when the moon is midway between the nodes. If the moon revolved around the earth in the plane of the equator, it would have no influence in producing precession. And if it revolved in the plane of the ecliptic there

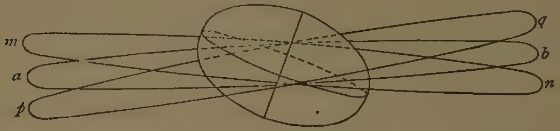


FIG. 135.—Cause of Nutation. The central elliptical figure represents the earth, and *ab*, the plane of the ecliptic. The moon's orbit is inclined about 5° to the ecliptic, but the line of intersection makes a revolution round the ecliptic in about 19 years. *mn* represents the orbit inclined to the ecliptic in the same direction as the earth's equator; the power to tilt the earth is then small. *pq* represents the orbit about 9½ years later, when the orbit is much inclined to the earth's equator, and the tilting power is great. These irregularities of the moon's action causes nutation.

would be no lunar nutation. But the orbit is inclined to the ecliptic at an angle of 5°, consequently the influence of the moon upon the equatorial protuberance of the earth must vary throughout the month. Further, the plane of the orbit, and therefore the line of nodes, moves round the ecliptic in 18 years 7 months, in much the same way that the plane of the earth's equator and the line of equinoxes shift around the ecliptic in 25,800 years. It is in consequence of this periodic change in direction of the moon's orbit that nutation is produced (Fig. 135). The fact that the declinations, longitudes, and right ascensions of stars increase and decrease by minute amounts in a period of 18 years 7 months, is in itself sufficient to show that the moon is responsible for the effects, for, as has been said, the line of nodes of the moon's orbit completes a revolution around the ecliptic in the same period.

Summary of Variations.—The variations described in the foregoing paragraphs have thus been summarised :—

1. The plane of the *ecliptic*, or of the earth's orbit, is a very slowly moving plane ; the movement is indeed so small that the plane may be regarded as fixed, except in delicate astronomical measurements.

2. The plane of the *equator* is a moving plane, but its inclination to the practically fixed plane of the ecliptic remains constant. The direction of the line in which it intersects that plane is, however, constantly changing, thus causing the precession of the equinoctial points.

3. The longitudes and right ascensions of stars are therefore subject to variations which do not arise from the motions of the stars, but from the shifting of the line of equinoxes, which is their common point of reference or origin. The declinations of stars are in like manner subject to variations because of the change of direction of the plane of the celestial equator.

4. As the differential attraction of the sun and moon upon the earth's equatorial protuberance does not disturb the position of the ecliptic, but only that of the equator and its intersection with the ecliptic, the nutation does not affect the celestial latitudes of stars, but only the celestial longitudes, right ascensions and declinations.

5. The effect of the above variations in the right ascension is felt to the full extent at the poles of the equator, that is,

of the heavens, and least at the equator, where they are almost inappreciable.

An important point to remember is that all these changes in the positions of the stars are only apparent changes due to variations in the positions of the planes or points of reference. The stars do, however, actually alter their relative positions of themselves; this *proper motion* is described on another page (p. 408).

CHIEF POINTS OF CHAPTER XIII.

The Celestial Co-ordinates used to determine positions upon the sky are :—(1) altitude and azimuth, (2) declination and right ascension, (3) celestial latitude and longitude. *Altitude* is the shortest angular distance from the horizon. *Azimuth* is angular distance from the south point of the horizon, measured in a plane parallel to the horizon.

Declination is angular distance north or south of the celestial equator. *Right ascension* is angular distance from the "first point of Aries," reckoned along the celestial equator.

Celestial latitude is angular distance from the ecliptic. *Celestial longitude* is angular distance from the "first point of Aries," measured along the ecliptic.

Rotation of the Earth.—The *fact* of rotation is proved by experiments with (*a*) Foucault's pendulum, (*b*) Foucault's gyroscope. The *exact time of rotation* is found by observations of stars with the transit instrument. The sun is not used in this determination because the interval between two successive transits of the sun's centre over a given meridian is not constant, as it is in the case of the stars, but varies from day to day.

Revolution of the Earth.—The *fact* of the earth's annual revolution round the sun is proved by the aberration of light. The orbit is an ellipse, and the sun occupies one of the foci. This is proved by measurements of the sun's angular diameter during a year.

Aberration of Light.—Due to the combination of the earth's velocity with the velocity of light. Result: every star is displaced 20″·5 from its mean position, in the direction in which the earth happens to be moving at the time of observation.

Precession.—Caused by the differential attraction of the sun and moon upon the equatorial protuberance of the earth. Result: earth's axis describes a cone in space. Consequences: (1) the line of equinoxes move in a retrograde direction along the ecliptic at the rate of 50″·2 per annum; (2) the sun meets the retrograding vernal equinox about twenty minutes earlier each year, this being about the time taken by the equinox to move back 50″·2. For this reason the tropical year is shorter than the sidereal year. (3) The poles of the equator describe circles round the poles of the ecliptic in 25,800 years. (4) The declinations of stars vary by about 47° during this period. (5) The right ascensions and longitudes of stars are annually increased.

Distinction between Aberration and Precession.—Aberration is a minute *annual* effect, and the displacement due to it is different in direction at different times of the year. Precession causes the apparent positions of stars to vary over a long period, and the direction of variation is the same throughout the year, though the amount varies according to the time of year.

Nutation.—A very small oscillatory motion of the earth's axis, caused principally by the action of the moon. Result: the celestial poles do not move evenly round the poles of the ecliptic in their precessional motion, but trace out a wavy line. Consequences: the plane of the equator is slightly affected, and therefore the declinations of celestial bodies; right ascensions and celestial longitudes are alternately increased and decreased by very minute amounts in a period of 18·6 years.

QUESTIONS ON CHAPTER XIII.

(1) What is the use of a transit instrument?

(2) How does the constant of aberration enable us to determine the distance of the sun?

(3) State what you know about the "aberration of light."

(4) What is the cause of the precession of the equinoxes, and how does this affect the apparent positions of the stars?

(5) What are the principal facts determined by the use of the transit instrument?

(6) How do we determine the time of rotation of the earth? Why is it that the sun is not employed in such an investigation?

(7) State the methods by which the rotation and revolution of the earth have been demonstrated.

(8) What are the causes of the apparent daily and annual motions of the stars?

(9) What are the principal effects of the precession of the equinoxes?

(10) How does Foucault's pendulum experiment demonstrate the true rotation of the earth?

(11) What is the cause and what is the result of the precession of the equinoxes?

(12) What are the causes of the apparent daily and annual motions of the stars?

(13) What is the aberration of light? How has it been determined?

(14) If the earth's equator were perpendicular to the plane of the ecliptic what changes would this give rise to in—

(*a*) The apparent daily movements of the stars.
(*b*) The seasons.
(*c*) The length of day and night?

(15) Describe the method of determining the position of a heavenly body by means of the transit circle.

(16) Describe a system of co-ordinates adopted in recording the positions of the heavenly bodies.

(17) Define altitude, declination, right ascension and zenith distance.

(18) Describe a gyroscope, and state how it may be used to demonstrate the rotation of the earth.

(19) Describe and explain the apparent movements of the stars to an observer, (*a*) in the British Isles, (*b*) at the equator, (*c*) at the North Pole.

(20) How has the shape of the earth's orbit been determined?

(21) A star is observed to be at a certain distance above the sun at sunset on a particular day. What difference would be observed a week later?

(22) Describe observations which show that the sun has an apparent motion among the stars.

(23) Describe and explain the sun's apparent annual motion among the stars.

(24) How do observations with the transit instrument enable precession to be determined?

CHAPTER XIV

THE UNIVERSE

THE LAW OF GRAVITY IN THE SOLAR SYSTEM

Introductory.—Before describing the action of the law of gravity in the solar system, it is necessary to explain what bodies make up the system, and to describe the features of their motions. The student probably knows that the earth is neither the only body, nor, indeed, the most important one, revolving round the sun. There are eight large globular bodies, called *planets*, travelling on regular paths, at varying distances, round our luminary. In the order of their distance from the sun these are :—

1 Mercury
2 Venus
3 Earth
4 Mars
5 Jupiter
6 Saturn
7 Uranus
8 Neptune.

In addition, there are about 450 much smaller bodies, known as the *minor planets* or *asteroids*, moving round the sun on orbits situated between those of Mars and Jupiter.

Six of these planets have smaller bodies, or *satellites*, revolving round them. Of these the earth has one, called the *moon*. The number of similar attendants in the case of the other five planets is seen from the table :—

Planet.	Number of Satellites.	Planet.	Number of Satellites.
Earth	1	Saturn	8
Mars	2	Uranus	4
Jupiter	5	Neptune	1

The gravitational attraction of the sun and planets has, at different times, drawn into our solar system about twenty *comets;* and these, like the planets, revolve round the sun —with the difference, however, that they move round it on orbits which are ellipses of a very elongated kind. Finally, there are swarms of little masses of rock of an ultra-basic nature (p. 206), called *meteorites*, which revolve round the sun in a manner very like the comets.

Distance of the Planets and their Periods of Revolution.—If the solar system could be viewed from the north pole of the heavens, the planets would all be seen revolving round the sun, at different distances from it, and in a direction opposite to that of the hands of a watch. Fig. 136 shows the comparative distances, drawn to a true scale, of the planets from the sun, and also their directions of motion.

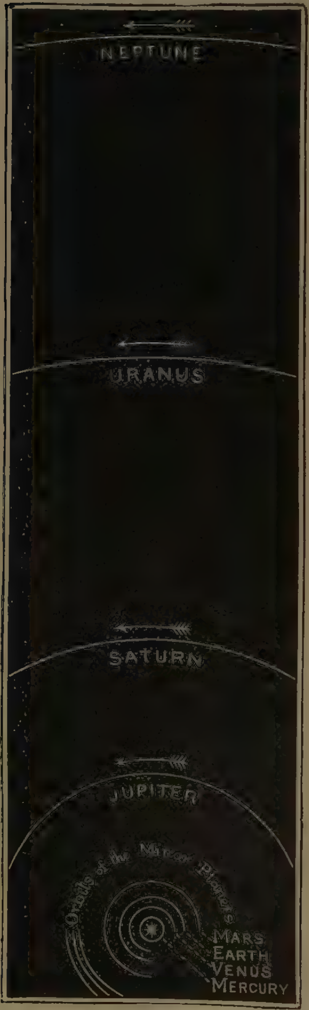


FIG. 136.—The Distances of the Planets from the Sun, drawn to a true scale.

The time taken by a planet to completely describe its orbit is known as its *sidereal period*, which ranges from three months in the case of Mercury, the planet nearest the sun, to nearly 165 years in the case of Neptune, the most remote. It is unnecessary for students of Physiography either to know exactly how many miles each planet is from the sun, or what exactly are its sidereal period and diameter; but a general idea of these numbers, such as is given in the following table,[1] should be obtained.

Name	Distance in terms of the Earth's Distance	Period of Revolution round the Sun	Diameter
Mercury . .	0·4	3 months	3,000 miles
Venus . . .	0·7	7½ months	7,700 ,,
The Earth .	1·0	1 year	7,918 ,,
Mars . .	1·5	1 year 10 months .	4,200 ,,
Asteroids .	3·0 ±	3 years to 9 years .	10 miles to 200 miles
Jupiter . .	5·2	11·9 years	86,000 miles
Saturn . .	9·5	29·5 ,, ...	73,000 ,,
Uranus . .	19·2	84·0 ,, ...	32,000 ,,
Neptune . .	30·1	164·8 ,, ...	35,000 ,,

The relative sizes of the sun and five of the Planets are shown in Fig. 137.

Eccentricity of Orbits of Planets.—The orbits of all the planets are elliptical, but the eccentricity of the ellipses (p. 298) differs for different planets. The most elliptical orbit is that of Mercury, with an eccentricity of 0·205 (the eccentricity of the earth's orbit is 0·017). The result of this is that the distance of Mercury from the sun varies from 28,500,000 miles, when it is nearest, to 43,500,000 miles when it is farthest away—a difference of 15,000,000 miles.

After Mercury, and excepting the asteroids and comets, the most eccentric orbit is that of Mars ($e = 0·093$). The orbit of Venus has the least eccentricity ($e = 0·007$), and consequently there is only a difference of 500,000 miles between its perihelion and aphelion distances.

Inclination of the Orbits of the Planets.—The planes containing the orbits of the different planets are slightly inclined to that containing the orbit of the earth, which is called the *plane of the ecliptic*. But this inclination is very slight. It is greatest in the case of the orbit of Mercury, where it is as much as seven degrees (7°).

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[1] From *Lessons in Astronomy*, by Prof. C. A. Young. Ginn and Co. 6*s*.

EXPT. 34.—Procure two small hoops or rings, one slightly larger than the other. Support the smaller one horizontally to represent the earth's orbit (its plane is therefore the plane of the ecliptic). Place the large hoop around the smaller one at varying inclinations to illustrate the inclinations of planetary orbits. Do not forget, however, that the inclinations of planetary orbits are too small to be actually shown by the experiment.

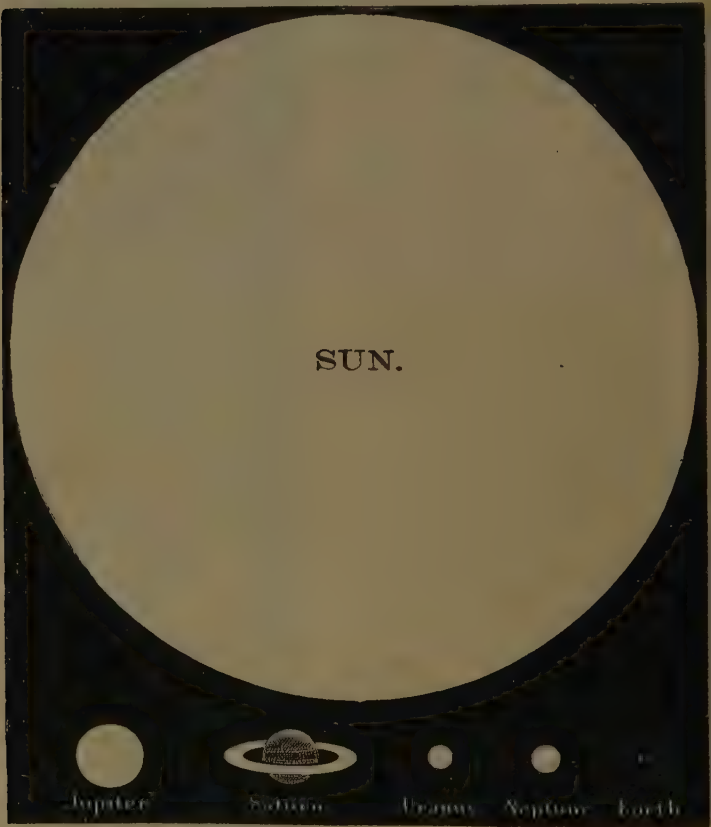

FIG. 137.—Relative sizes of the Sun and some of the Planets.

EXPT. 35.—Show that not only may the inclinations of the hoops differ, but also the directions of the line connecting the two points where the planes of the hoops intersect.

The line along which the plane of a planet's orbit intersects the plane of the ecliptic is termed the *line of nodes*. The *nodes* are the points where the planet's orbit itself cuts the plane of the ecliptic. Of these nodes, that which marks the place where a planet passes from south to north of the ecliptic is called the *ascending node*, while the other is the *descending node*. Evidently when an object, whether it is a planet or a satellite, is at a node it is of necessity on the ecliptic.

Apparent Motions of Planets.—The motion which a planet appears to have when viewed from the earth is by no means as simple as that which it would seem to have if it could be watched from the north pole of the heavens. The earth is a moving observatory, and it is its motion which produces the complication. It will be sufficient for our purpose to describe the phenomena in the case of one planet, and we will take Mars.

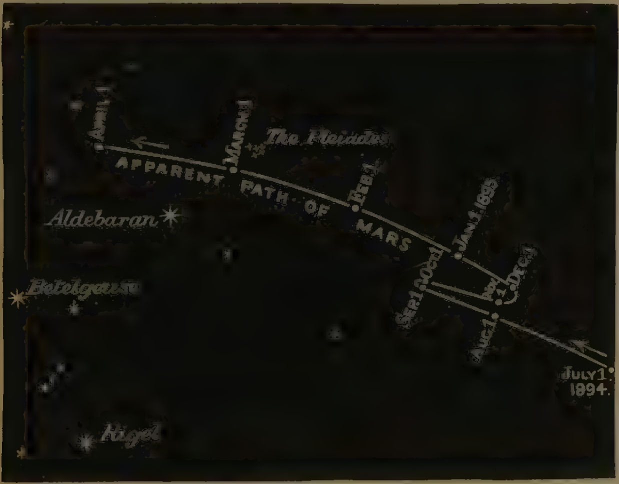

FIG. 138.—Apparent Path of the Planet Mars among the Stars during 1894 and 1895.

Fig. 138 shows the apparent path of this planet among the stars during the years 1894 and 1895. It is seen that the path over which the planet appears to move is looped in a characteristic fashion, which is easily understood by a careful examination of

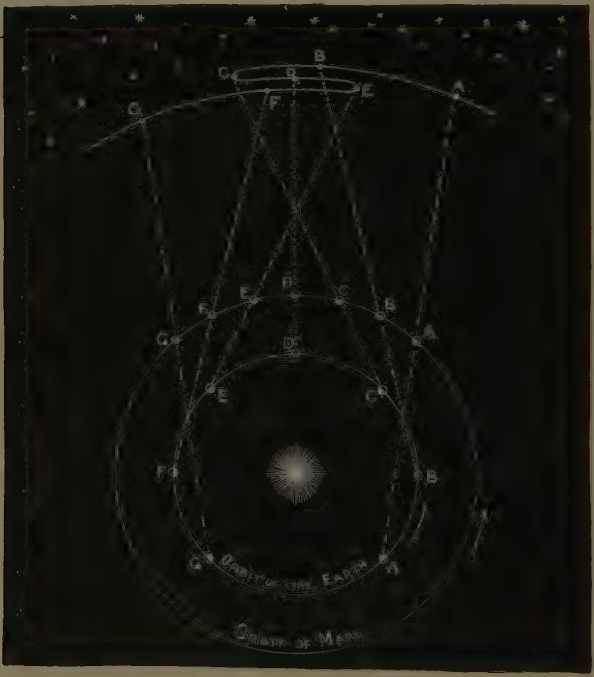

FIG. 139.—To explain the Apparent Path of Mars among the Stars. It will be seen that the motion of the Earth from A to G, while Mars moves from A to G in its own orbit, causes the latter to appear to move in a looped path among the stars.

Fig. 139, in which various positions of the earth and Mars on their orbits are shown. The period of Mars is one year ten months as compared with one year in the case of the earth. While the earth is moving from A to B on its orbit, Mars is similarly moving from A to B on its own orbit, and the succeeding positions of the two bodies after equal intervals of time are shown by consecutive letters. The dotted lines, passing through corresponding positions of the earth and the planet under observation, locate the apparent situation of the planet in space to a terrestrial observer, and if these localities are joined by a curve the looped path which is shown in the figure is obtained.

It may here be mentioned that when a planet or any other member of the solar system is moving eastward *among the stars* it is said to be in *direct* motion, whereas motion towards the west is described as *retrograde.*

Designation of Planetary Positions.—A planet is said to be in *conjunction* when it appears in a line with the sun, and so comes on the meridian at the same time; it is in *inferior conjunction* if it is between the earth and the sun, and in *superior conjunction* if on the remote side of the sun. When the earth is not only in the same straight line with the planet and the sun,

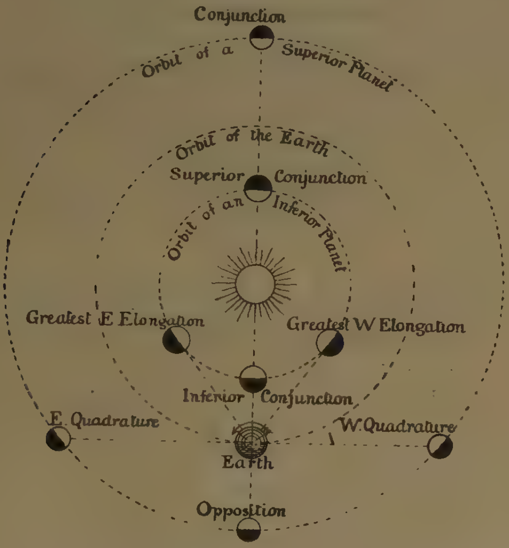

FIG. 140.—Designation of Planetary Positions.

but between the two, the planet crosses the meridian at midnight, and is under these circumstances said to be in *opposition.* The apparent angular distance between the position of the sun and that of a planet, as observed from the earth, is known as the *elongation* of the planet. When the elongation is ninety degrees (90°) the planet is in *quadrature.* It will be at once perceived that when the elongation is 0°, a planet is in conjunction, and when it is 180° the planet is in opposition. Only planets outside the earth's orbit, or, as they are called, *superior planets*, can be in opposition (Fig. 140).

Sidereal and Synodic Periods.—The sidereal period of a planet is the true time of its revolution round the sun ; but, as has been before remarked, the earth is a moving observatory, so the motion of a planet from our point of view differs from the motions we should observe if we were situated upon the sun. If we take the interval between two conjunctions or two oppositions of a planet, we get what is termed the *synodic period*, which may be defined as the interval between the times when the sun, planet, and earth occupy the same relative positions. The sidereal period of a planet, the synodic period, and the earth's sidereal period or year, are connected as follows :—

For an inferior or interior planet, that is, one between the earth and the sun—

$$\frac{1}{\text{Synodic period}} = \frac{1}{\text{Sidereal period}} - \frac{1}{\text{year}}$$

For a superior or exterior planet, that is, one further from the sun than the earth—

$$\frac{1}{\text{Synodic period}} = \frac{1}{\text{year}} - \frac{1}{\text{Sidereal period}}$$

The synodic period can thus be determined when the sidereal period is known, and *vice versa.*

The Zodiacal Light.—In winter and spring a soft, faint column of light may be seen rising from the western horizon after sunset ; or it can be seen above the eastern horizon shortly before sunrise in summer and autumn. This is the zodiacal light. It is a lens-shape formation of some sort, extending from the sun to a little beyond the earth's orbit, and lying very nearly in the plane of the orbit—that is, the plane of the ecliptic. It may be an extremely rare atmospheric appendage surrounding the sun, or (and this is more likely) it consists of an immense cloud of meteoritic particles filling the space between the earth and the sun. If this is the case, the light seen is only reflected sunlight. But whether its matter is gaseous or meteoritic, it certainly belongs to the solar system, and must therefore be mentioned here.

THE LAW OF GRAVITY IN THE SOLAR SYSTEM

Introductory.—It will be advisable, in order to simplify this part of the subject as much as possible, to revise some of the fundamental truths upon which it depends. With this object in view a brief summary of certain dynamical conceptions which the reader has probably studied before will be given, and he will then be better able to appreciate the results referred to later.

Laws of Motion.—These laws, or statements of experience, which Newton formulated, may be simply expressed as follows:—

1. A body once set in motion and acted upon by no force will move forward in a straight line with a uniform velocity for ever.
2. If a moving body be acted upon by any force, its deviation from the motion defined in the first law will be in the direction of the acting force and proportional to it.
3. Action and reaction are equal, and in opposite directions.

First Law.—The first law of motion gives us definitions both of *inertia* and *force*. Inertia is the inability shown by a material body of itself to change its condition of rest, or of uniform motion. Force is that which produces, or tends to produce, motion in matter; or alters, or tends to alter, the existing motion of matter. But, here again, it must be insisted, that defining force in this manner adds nothing to our knowledge of what it is. All we can know of the nature of force are the effects which it can produce. Another way of regarding this first law of motion is as a statement of the impossibility of perpetual motion under the conditions which obtain on the surface of the earth. Perpetual motion is here impossible, because we cannot eliminate all the impressed forces acting upon moving bodies—they are always impeded by a certain amount of friction and often by other outside forces, and hence, sooner or later, come to rest.

Second Law.—This law is generally stated by saying that "change of motion is proportional to the impressed force, and takes place in the direction in which that force acts." This expression, "change of motion," implies something more than the conception of motion as a mere change of place. By "change of motion" is meant *rate of change of momentum* or quantity of motion, which is equal to the product of the body's mass into its velocity. The unit of momentum will consequently be that of a unit of mass moving with a unit of velocity.

The second law of motion states that the momentum generated by a force of two units will be twice as great as that produced by one unit; and it implies, moreover, that a force of one unit acting for two seconds will produce twice the momentum which it would do if it only acted for one second. This is why it is necessary in defining the unit of force to introduce the words "acting for a unit of time."

The principle of the parallelogram of forces is an immediate outcome of this law. If a body is acted upon by two forces in directions inclined to one another at an angle, since the body cannot move in two directions at the same time, it will move in some intermediate direction, which can be determined in the following way. Let O represent a material body acted upon by two forces, represented both in amount and direction by the lines OB, OA. To find the *resultant* of these two forces, both as regards its amount and direction, we complete the parallelogram OBRA and join OR, which will be the resultant required. Conversely, if we have a force OR, we can split it up into any two *component* forces, by constructing a parallelogram about it, when the two adjacent sides OA, OB, will represent such components both in magnitude and direction. By trial the student will find that an infinite number of such parallelograms can be constructed, but in practice it is usual in *resolving* a force to do so into two components at right angles to one another.

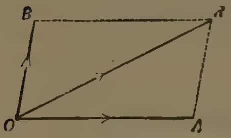

FIG. 141.—The Parallelogram of Forces.

Third Law.—This statement, that action and reaction are equal and opposite, carries with it the inference that every force is one of a pair of forces, the second being the reaction to which the first gives rise. This pair of forces constitutes a *stress;* and *tension*, *attraction*, *repulsion*, etc., are all examples of stresses.

Mass.—This term has already been used, and will have to be employed so frequently during the progress of the chapter that, at the risk of repetition, we must again draw attention to its exact significance. The mass of a body is not its weight, but the amount of matter it contains. The force with which a given mass is attracted by the earth, or what, as we have seen is, by Newton's third law, the same thing, the force with which it attracts the earth, is the weight of the mass. Everyday experience tells us that a certain amount of effort must be put forth in order to counterbalance the weight of bodies. This effort is not the same for a given volume of different substances; it differs, for instance, when equal volumes of water, iron, and mercury, are supported. The proper idea of mass comes from these different weights of equal volumes.

Acceleration.—Imagine any mass at rest, and suppose it to come under the influence of a force acting in one direction and of constant intensity. Such a mass will acquire a certain velocity in the first second during which the force acts, the same velocity in the second second, and so on. That is to say, its motion will be uniformly accelerated. Bodies falling *in vacuo* under the influence of gravity afford the best example or such accelerated velocity. In general, when the acting force increases in a certain ratio, the acceleration increases in the same ratio. This fact provides us with a means of comparing forces by observation of their ability to produce motion. A force will be double, treble, ... stronger than another force if it produces when acting upon the *same* body double, treble, ... etc., the acceleration.

If two bodies of different volumes are taken and subjected to the action of the same constant force, and it is found that equal accelerations are produced, we at once conclude that though the volumes are unequal the masses of the two bodies are equal. We are thus able to determine the equality of masses by means of the action of equal forces upon them. Thus, in the case of bodies having masses respectively represented by the numbers 1, 2, 3, ... acted upon the same force in turn, we shall have accelerations represented by 1, $\frac{1}{2}$, $\frac{1}{3}$, ... imparted to such bodies. These facts are best summarised by a simple algebraical expression. Let F represent the number of units of force acting upon a body containing m units of mass which are necessary to produce in it a units of acceleration, then—

$$\text{Force} = \text{mass} \times \text{acceleration};$$

or,
$$F = m \times a.$$

Therefore,
$$m = \frac{F}{a}$$

Falling Bodies. Acceleration of Gravity.—One of the earliest observations made by every person is that bodies free to move gravitate, as we say, to the earth. Or, in commoner words, all bodies under these circumstances are attracted by the earth and move towards, or fall upon, it. Later we find that they move towards the earth with a constantly accelerated velocity. The acceleration due to this stress of attraction, which we colloquially speak of as the force of gravity, is the same for all bodies. A body whose mass is 100 lbs is attracted with 100 times the force of a body whose mass is 1 lb, but since there are 100 times as much matter to move, the velocity is the same in both cases. Pendulum bobs of different materials vibrate in the same time if the lengths of suspension are equal in all cases.

It will be worth while to reconsider the case of a body falling towards the earth. Think of a cricket ball on the top of a house. The earth attracts the ball, and, by Newton's law, the ball attracts the earth. The ball, if free to move, falls to the earth; to be correct, however, we must think of the ball and the earth moving to meet one another along the line joining their centres, with a momentum which is equal in both cases. Since, however, the mass M of the earth is so immensely greater than that m of the cricket ball, the velocity V with which the cricket ball moves will be correspondingly greater than that v with which the earth moves. This can be simply expressed thus:—

$$\text{Momentum of the earth} = Mv$$
$$\text{Momentum of cricket ball} = mV.$$

But,
$$Mv = mV$$

Therefore,
$$\frac{V}{v} = \frac{M}{m};$$

or,

$$\frac{\text{Velocity of cricket ball}}{\text{velocity of earth}} = \frac{\text{mass of earth}}{\text{mass of cricket ball}}.$$

Relation between Space described by, the Acceleration produced in, and the Time of falling of, Bodies moving towards the Earth.—If the space described by a body falling from rest is S units of length, and the time through which it falls is t seconds, and the acceleration due to gravity be g units of acceleration, a relation can be found connecting these numbers, as explained on p 19. It is there shown that the space (S) traversed by a falling body is the product of its average velocity ($\frac{1}{2}v$) and the interval of time t, or

$$S = \frac{1}{2}vt.$$

In the case of a body moving from rest the acceleration is produced by gravity. At the end of the first second, therefore, the body has a velocity of g feet per second, at the end of the next second $2g$ feet per second, at the end of t seconds gt feet per second. Or, since v = change of velocity in t seconds, we can write—

$$v = gt.$$

Substituting this value in our previous equation we get—

$$S = \frac{1}{2}gt \times t$$
$$S = \frac{1}{2}gt^2.$$

Law of Gravitation.—Experiments and observations made by Newton led him to the conclusion that it was the rule of nature for every body to attract every other body, and that this force of attraction is proportional to the body's mass, a large mass exerting a greater force of attraction than a small mass. But the farther these bodies are apart the less will be the attraction between them, though it is not less in the proportion of this distance but in that of the square of the distance. This diminution of a force according to the inverse proportion of the square of the distance applies to so many cases that it must be clearly understood. To give an example: two bodies of equal mass are one foot away from one another and attract each other with a certain force; call it a unit force. One body is now moved until its distance is two feet away from the second body what will be the force of attraction between them? The square of 2 is $2\times 2=4$ and the inverse of 4 is a $\frac{1}{4}$, therefore the force of attraction is one quarter of the unit force. Putting Newton's law together it stands thus. *Every body in nature attracts every other body with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them; and the direction of the force is in the line joining the centres of the bodies.*

Fall of Moon towards the Earth.—At the earth's surface a body falling freely *in vacuo* has a velocity of 32·2 feet per second after falling for one second, which is, therefore, the acceleration due to gravity. The space through which it falls in this interval of time is one half of this acceleration, or 16·1 feet, as we can see by substituting in the equation at the end of the last paragraph but one these values for g and t—

$$S=\tfrac{1}{2}\times 32{\cdot}2\times 1^2=16{\cdot}1 \text{ feet.}$$

This value for S is the extent of fall towards the earth in one second at a distance of 4,000 miles roughly from its centre. Now the moon's distance from the earth is 240,000 miles,[1] that is 60 times further away, $\left(\text{for } \frac{240{,}000}{4{,}000}=60\right)$; and consequently for a body at the distance of the moon the fall per second would be, if Newton's law of gravitation be assumed to be true, less in the proportion of the square of the distance, or—

$$\text{Fall of a body at the distance of the moon in one second}=\frac{16{\cdot}1 \text{ feet}}{60^2 \text{ feet}}=\frac{16{\cdot}1}{3{,}600}=\mathbf{0{\cdot}004 \text{ feet.}}$$

Proof of Law of Gravitation.—Now let us see what the fall of the moon towards the earth actually is; in other words, what the amount of the deviation is in one second from the tangent, along which, because of its inertia, it would move if there were no earth to exert any attractive influence upon it.

Moon's distance = 240,000 miles
Circumference of moon's orbit = 1,508,000 miles.

And this latter length is described in 27 days 7 hours 43 minutes (=2,360,580 seconds).

$$\text{Distance traversed by moon in 1 second}=\frac{1{,}508{,}000}{2{,}360{,}580}=0{\cdot}639 \text{ miles.}$$
$$=3{,}374 \text{ feet}=\text{AC (Fig. 142).}$$

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[1] *Physiography for Beginners*, p. 188.

To find the length of BC we must make use of a proposition in Euclid (III. 36) which tells us that—

$$AB^2 = 2\,CD \times BC \text{ (nearly),}$$

i.e. $$AB^2 = \text{diameter of moon's orbit} \times BC \text{ (nearly)};$$

$$\therefore \quad BC = \frac{AB^2}{\text{diameter of orbit}}.$$

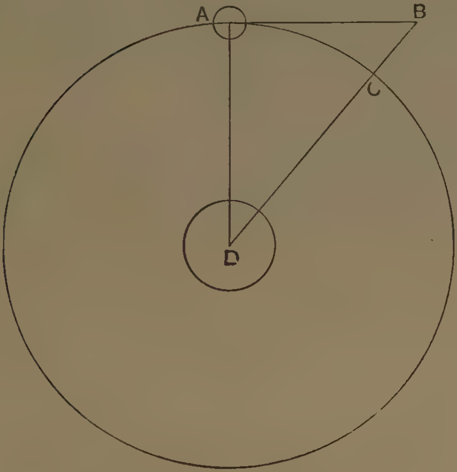

FIG. 142.—The Fall of the Moon towards the Earth.

But since AB is very nearly equal to AC we can write—

$$\begin{aligned} BC &= \frac{AC^2}{\text{diameter of orbit}} \\ &= \frac{(0{\cdot}639)^2}{480{,}000} \text{ miles} \\ &= 0{\cdot}0045 \text{ feet}; \end{aligned}$$

therefore,

$$\frac{\text{Fall per second at moon's distance}}{\text{Fall per second at earth's surface}} = \frac{0{\cdot}0045}{16{\cdot}1} = \frac{1}{3600} \text{ nearly.}$$

Hence, the force of the earth's attraction at the distance of the moon is found to be actually 1/3600 the force at the earth's surface. Thus, so far as the moon is concerned, the law of gravitation is demonstrated.

Kepler's Laws.—Before Newton had enunciated the law of gravitation, Kepler had laid down the three laws, known by his name, which he had arrived at by observation of the planets. It was shown by Newton that the rules recognised by the earlier astronomer were fully explained by the law of gravitation, thus showing that gravitation acts throughout the solar system.

Kepler's three laws may be stated as follows:—

1. The planets revolve round the sun in orbits which have the form of ellipses. The sun is situated at one of the foci of the ellipse.

2. The areas swept over by the radius vector of each planet are equal in equal times.

3. If the squares of the times of revolution of the planets round the sun be divided by the cubes of their average distance from the sun, the quotient will be the same for all the planets.

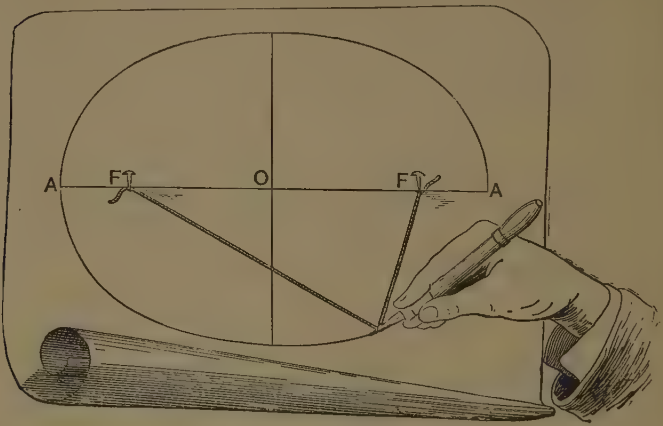

FIG. 143.—Construction of an Ellipse.

Kepler's First Law.—Before the student can understand this law, he must first learn some of the properties of the ellipse.

EXPT. 36.—Fix a pin into a piece of paper and pass a loop of thread over it. Into the other end of the loop push a piece of pencil. Keeping the thread tight, draw a line on the paper round the pin. Remove the thread, and notice that a *circle* has been described with the pin as its centre.

EXPT. 37.—Fix two pins into the paper, and pass the loop over both pins, and again move the pencil round as before. Notice that this figure is not a circle. It is an *ellipse*, and the pins are situated at points called the *foci*, (Fig. 143.)

EXPT. 38.—Repeat the last experiment several times, with the pins nearer and nearer together. Notice that the closer the pins are together the more nearly does the ellipse approach the shape of a circle. We can look upon a circle as an ellipse where the two foci have moved up together until they occupy the same point.

The first law, then, simply states that the figures which the planets trace out as they move round the sun are similar in shape to that marked out by the pencil in Expt. 36, and that the sun occupies the position of one of the pins round which the loop of thread is passed. If this is true of all the planets it must be true of our earth, and consequently we must be nearer to the sun at certain times than at others. Moreover, if we are nearer to the sun at some times of the year than at others, the sun ought to appear larger than when we are as far away as we can be. This is found to be the case. If the diameter of the sun is measured at noon on Midwinter day, and again at noon on Midsummer day, it is found to appear larger on the former occasion. Fig. 144 gives an idea of the amount of this difference.

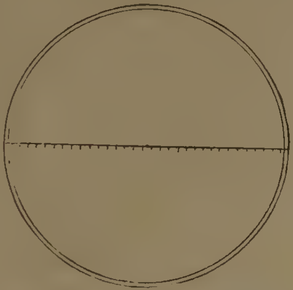

FIG. 144—To show the difference in the apparent size of the Sun on Midwinter and Midsummer Day.

Kepler's Second Law.—The areas swept over by the radius vector of each planet are equal in equal times.—By the radius vector is meant an imaginary line joining the centre of the planet with that of the sun. Fig. 145 shows that it cannot remain of the same length. When the planet is nearest the sun, or as it is called, in *perihelion*, the radius vector is much shorter than when it is farthest removed, or in *aphelion*. The shaded portions of the figure represent areas moved over in equal times by this imaginary line, and the second law states that they are all equal. It follows as a necessary consequence that the distance $P_2\,P_3$ moved by the Earth, for example, when this planet is near the sun, must be greater than $P_4\,P_5$, the distance traversed when the Earth is aphelion. But these distances are travelled in the same period of time, and consequently Kepler's second law is tantamount to saying that the planet moves more quickly in perihelion than when in aphelion. This is found to be the case with the Earth ; for whereas the passage from the autumnal to the spring equinox takes 179 days, that from the spring equinox to the autumnal takes seven days longer.

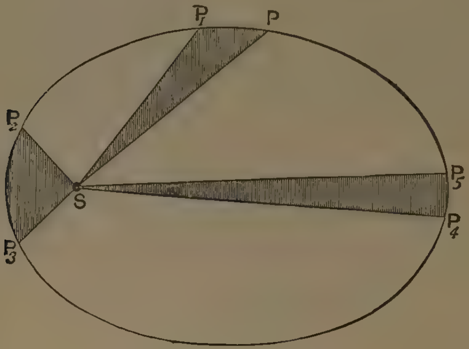

FIG. 145.—To explain Kepler's Second Law.

Kepler's Third Law.—If the squares of the times of revolution of the planets round the sun be divided by the cubes of their average distance from the sun, the quotient will be the same for all planets.

The time of revolution of a planet round the sun is called its *period.* This law is best understood by an example, say, the Earth and Saturn. Following the rule, we can write—

$$\frac{(\text{Earth's period})^2}{(\text{Earth's average distance})^3} = \text{some quotient, say } x,$$

$$\frac{(\text{Saturn's period})^2}{(\text{Saturn's average distance})^3} = \textit{same} \text{ quotient } x,$$

$$\frac{(\text{Earth's period})^2}{(\text{Earth's average distance})^3} = \frac{\text{Saturn's period})^2}{(\text{Saturn's average distance})^3}$$

Therefore, knowing the Earth's period and its average distance, we could find Saturn's average distance if we knew its time of revolution. The Earth's period is one year, and Saturn's $29\frac{1}{2}$ years; and from the last equation above we can write—

$$\begin{matrix}\text{Square of} & & \text{Square of} & & \text{Cube of} & & \text{Cube of}\\ \text{Earth's} & : & \text{Saturn's} & = & \text{Earth's} & : & \text{Saturn's}\\ \text{period.} & & \text{period.} & & \text{distance.} & & \text{distance;}\end{matrix}$$

or,

$$1 : 29\tfrac{1}{2} \times 29\tfrac{1}{2} = 1 \times 1 \times 1 : \text{cube of Saturn's distance, that is,}$$

$$\begin{matrix}\text{Cube of Saturn's}\\ \text{distance}\end{matrix} = 870\tfrac{1}{4} \text{ times Earth's distance.}$$

$\therefore$ Saturn's distance $= 9\frac{1}{2}$ (very nearly) times the Earth's distance.

The truth of the third law is also shown by the subjoined table:—

Planets	Mean Distance	Periodic Time	$\frac{\text{Periodic Time}^2}{\text{Mean Distance}^3}$
Mercury . . .	0·38710	87·969	133,421
Venus	0·72333	224·701	133,413
Earth	1·00000	365·256	133,408
Mars	1·52369	686·979	133,410
Jupiter	5·20277	4332·585	133,294
Saturn	9·53858	10759·220	133,375
Uranus	19·18239	30686·821	133,422
Neptune . . .	30·03627	60126·722	133,413

Determination of Masses in Astronomy.[1]—It follows from the principle ($F = ma$) laid down in the early part of the chapter that, to compare the masses of the sun and the different planets, we might apply a given force to them and measure the acceleration produced, when the masses would be inversely proportional to the accelerations produced in them. This method is not, however, practicable, though the law of gravitation allows it to be transformed.

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[1] A free translation of parts of an article by the late M. Tiserand in the *Annuaire du Bureau des Longitudes*, 1889.

Suppose that the same body was placed successively at equal distances from the sun and earth ; it would be attracted with forces which would be proportional to the masses of these heavenly bodies. Moreover, the accelerations produced would also be proportional to the masses of the sun and earth, and it would be found that if the object fell one inch towards the earth in a second, it would fall 330,000 inches towards the sun in the same time. We should thus conclude that the sun's mass was 330,000 times greater than that of the earth. It is not, however, necessary to place the hypothetical body at the same distance from the sun and earth ; for if we suppose, for instance, that the body be ten times nearer to the earth than to the sun, we can divide the fall per second by 100 (*i.e.*, $10 \times 10 = 10^2$), and so place the sun and earth on equal footings.

Application of the Foregoing Principle.—*Calculation of the relative masses of the sun and earth by a comparison of the fall of the moon to the earth and the earth to the sun.*—Let *d* (Fig. 146) represent the earth, *Acei* the orbit which the moon describes round it, A the moon's position on this orbit at any given moment, AO the moon's velocity at that moment, and *c* the position which the moon actually occupies a second after passing the point A. At A the moon's movement is determined by the combination of two influences : the velocity which the moon possesses at A, and the attraction which the earth exercises upon it. In the absence of this attraction the moon would arrive at O at the expiration of a second ; but, since it is found at *c*, we conclude that the amount *oc*—the deviation from the straight line course—represents the amount by which the moon falls towards the earth in one second. If we regard the moon's orbit as a circle (and it is practically circular) the calculation of the length *oc* is very simple (p. 323) ; and, even in the case of elliptical orbits, the calculation of *oc* is not difficult.

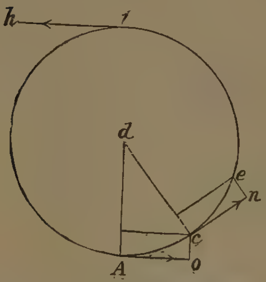

FIG. 146.—To illustrate the motion of one body around another in a circular path ; for instance, the motion of the Moon around the Earth.

Evidently any point on the orbit could be taken, for instance, *c* instead of A, and the position of the moon could be similarly explained. If the earth's attraction ceased when the moon arrived at *i*, the moon would fly away into space in the direction *ih*.

We ought now to determine the distance which the moon falls towards the sun in a second; but what is really done is to find the distance which the earth falls towards the sun in a second. It may be objected that the fall of the *moon* towards the sun is required, *not* the fall of the earth. But, as a matter of fact, it makes no difference which is taken, for *in vacuo* all bodies fall with equal velocities (p. 322). Referring again to Fig. 142, D may be taken to represent the sun, and A the earth, whose orbit may for our purpose be regarded as circular, as in the figure. It is found that in one minute the earth falls towards the sun 35·64 feet, while the moon towards the earth 16·1 feet in the same time. But the moon is 386 times nearer to us than the sun; so that, if it were removed to the same distance from us as the sun, the fall per minute would be $\frac{16\cdot1}{(386)^2}=0\cdot000108$ foot. Therefore, the mass of the sun is to the mass of the earth as 35·64 is to 0·000108, that is, as 330,000 is to 1.

In other words, the sun's mass is roughly 330,000 times greater than the earth's.

Another Method of Determining the Mass of the Sun.—The mean fall of the earth to the sun is 0·0097 foot in one second, and this is due to the sun's attraction at a mean distance of 92,897,000 miles from the centre of the sun. Now at a distance from the sun's centre equal to that between the centre of the earth and the surface, that is, half the length of the earth's diameter, or 3,960 miles, the attractive force of the sun would be much greater, and the fall of the earth towards the sun's centre would be correspondingly greater. It would be—

$$\left(\frac{92,897,000}{396}\right)^2 \times \cdot0097 \text{ foot} = 5,338,832 \text{ feet in one second.}$$

$$\therefore \frac{\text{Mass of sun}}{\text{Mass of earth}} = \frac{5,338,832}{16\cdot1} = 331,000.$$

Hence, we see that the sun's mass is roughly 331,000 times greater than the earth's.

Mass of a Planet with Satellites.—The preceding principles are of general application, and may be used to determine the mass of any planet having one or more satellites. It is only necessary to know the major axis of the planet's orbit and those of its satellites, together with the periods of revolution in their orbits, and both these quantities can be found by observation. Now, the sun is the centre of motion of the movement of a planet in its orbit, while the latter is similarly the centre of motion of a satellite. Hence, by a comparison of the planet's orbit with that of its satellite, we find the comparative attractions, and therefore the comparative masses, of the sun and planet, thus :—

$$\frac{\text{Mass of sun}}{\text{Mass of planet}} = \frac{\dfrac{(\text{Planet's mean distance, } A)^3}{(\text{Planet's period, T})^2}}{\dfrac{(\text{Satellite's mean distance, } a)^3}{(\text{Satellite's period, } t)^2}}.$$

Therefore,

$$\text{Mass of Planet} = \text{Mass of Sun} \times \left(\frac{a^3}{t^2} \times \frac{\mathrm{T}^2}{\mathrm{A}^3}\right)$$

By similar reasoning we may say the earth is the centre of the moon's orbit and any planet under consideration is the centre of its own satellite's orbit, and we may write—

$$\frac{\text{Mass of earth}}{\text{Mass of planet}} = \frac{\dfrac{(\text{Moon's mean distance})^3}{(\text{Moon's period})^2}}{\dfrac{(\text{Satellite's mean distance})^3}{(\text{Satellite's period})^2}}.$$

When a planet's mass compared with that of the earth has been found, its density can be determined immediately from the definition of mass—

$$\text{Mass} = \text{volume} \times \text{density}.$$

Therefore,

$$\text{Density} = \frac{\text{mass}}{\text{volume}},$$

when all the quantities are expressed in suitable units, which shows that all we have to do to determine the density of a planet is to divide its mass by its volume.

In the case of Jupiter the mass of the planet can be determined from the orbits of each of its satellites, and the results may be used to check one another and provide an accurate mean value of the planet's mass.

Saturn's mass has been found by observations of the two largest satellites, Titan and Japetus. The masses of Mars, Uranus, and Neptune have all been determined in the same way.

There are other methods by which the masses of these planets have been found, viz., by observing the effects produced upon comets and other bodies which happen to pass in their neighbourhood.

Masses of Planets without Satellites.—The planets which have no satellites, Mercury and Venus, present a more difficult problem in the determination of masses. What is done is to find the perturbations which planets of known mass produce upon them and the perturbations which they produce upon one another, but this determination cannot be made very exactly.

CHIEF POINTS OF CHAPTER XIV.

The Solar System consists of (1) the sun; (2) eight large planets, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, Neptune; (3) nearly five hundred asteroids; (4) twenty-one satellites; (5) a number of periodical comets, and swarms of meteorites; (6) the zodiacal light.

The Orbits of the Planets are all elliptical, but they differ in size, eccentricity, inclination, and direction of major axis. The direction of motion is the same in each case, but the rates of motion are different.

Apparent Motions of Planets.—Seen with reference to the stars, a planet moves forward, stops, moves backwards, stops, and moves forward again, when observed for several months. These are apparent movements caused by the motion of the planet in its orbit, and the orbital motion of the earth. Motion towards the east is described as *direct* motion, and motion towards the west as *retrograde*.

Planetary Aspects expressed in Angles.—*Elongation* is angular distance between the position of a planet and that of the sun. At *conjunction*, the elongation $=0^\circ$; at *quadrature*, the elongation $= 90^\circ$; at *opposition*, the elongation $= 180^\circ$.

Sidereal and Synodic Periods.—The *sidereal period* of a member of the solar system is the true period of revolution round the sun; the *synodic period* is the period between two successive presentations of the object in the same position with reference to the sun and earth.

First Law of Motion.—Every body remains at rest, or continues in motion in a straight line, unless it is compelled to change that state by a force acting upon it.

Second Law of Motion.—Change of motion is proportional to the acting force, and takes place in the direction in which the force acts.

Third Law of Motion.—Action and reaction are equal and opposite; or the mutual actions of two bodies on one another are always equal and in opposite directions.

The Law of Gravitation.—Every particle in nature attracts every other particle with a force which is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them.

$$\text{Gravitational attraction} = \frac{\text{Mass} \times \text{mass}}{\text{square of distance between them.}}$$

$$\text{Force} = \text{mass} \times \text{acceleration.}$$

$$\text{Momentum} = \text{mass} \times \text{velocity.}$$

Falling Bodies.—The following equations can be applied to bodies falling from rest:—

$$\text{Space traversed} = \tfrac{1}{2}(\text{velocity} \times \text{time}).$$

$$\text{Space traversed} = \tfrac{1}{2}(\text{acceleration} \times \text{time}^2)$$

$$(\text{Velocity}^2) = 2\,(\text{acceleration} \times \text{space traversed}).$$

The acceleration due to gravity is 32·2 feet per second; the space described by a body falling from rest is 16·1 feet in the first second. Assuming that the law of gravitation can be applied to the moon, the fall of the moon to the earth in one second is found to be 0·004 feet. This proves to be the exact amount by which the moon deviates from a tangent to its orbit in one second; the moon's motion is thus proved to be governed by gravitation.

Kepler's Laws.—(1) Each planet revolves in an ellipse with the sun at one of the foci; (2) equal areas are swept over in equal times by a line joining the planet to the sun; (3) the squares of the revolution periods are proportional to the cubes of the mean distances.

Determination of the Mass of the Sun.—The relative masses of the sun and earth are determined by comparing the fall of the moon to the earth with the fall of the earth to the sun in the same time, and then reducing the values to equal distances.

Determination of the Mass of a Planet.—Compare the fall of the satellite of a planet towards its primary with the fall of the moon towards the earth in the same time, and reduce the results to equal distances. This gives the mass of the planet relatively to the earth's mass. To find the mass in comparison with the sun, the fall of a satellite towards its primary is compared with the fall of the planet towards the sun in the same time, and the results are reduced to equal distances.

QUESTIONS ON CHAPTER XIV.

(1) How is the synodic period of a planet determined, and how can the periodic time be deduced from this; (*a*) in the case of an interior planet; (*b*) in the case of an exterior planet?

(2) State how the mass of the sun is determined in terms of the mass of the earth.

(3) How has the mass of Jupiter been determined?

(4) What is the synodic period of a planet?

(5) Define fully (by diagram or otherwise) the meanings of the following terms:—

Gibbosity.	Elongation.	Opposition.
Conjunction.	Stationary points.	Synodic period.

(6) What bodies constitute the solar system?

(7) Describe and explain the looped path which a planet appears to traverse among the stars.

(8) Distinguish between the sidereal period and the synodic period of a planet.

(9) Show that the parallelogram of forces is a consequence of the second law of motion.

(10) Define acceleration, and state how it is related to force and mass.

(11) Describe the relation between space, acceleration, and time, and show how it may be applied to the case of bodies falling towards the earth.

(12) Calculate the fall of the moon towards the earth in one second, having given that the acceleration due to gravity is 32·2 feet per second at the earth's surface. Compare your result with the actual fall of the moon towards the earth in a second.

(13) The sidereal period of a certain asteroid is found to be eight years. Determine, by means of Kepler's 3rd law, the distance of the planet from the sun, in terms of the earth's distance.

(14) How is it that planets revolve round the sun instead of falling into it?

(15) Apply the parallelogram of forces to explain the motion of a planet in an orbit round the sun.

(16) Describe the principle of a method used to determine the mass of the sun.

(17) How can the mass of a planet be determined by observations of the satellites?

(18) Give some of the reasons for concluding that the law of gravity controls the motions of bodies in the solar system.

CHAPTER XV

THE UNIVERSE

PHYSICAL FEATURES OF THE SUN AND MOON

The Sun.—The student has already learnt to regard the sun as the source of all the forms of energy which we have found to exist on the earth. He has seen that this energy leaves the sun as radiations, which by processes of transmutation become known to us here under the forms of heat, light, chemical action, and so on. It is desirable that we should now inquire further into the nature of the sun.

The sun is the nearest star to the earth; we learn in a general way to regard it as something distinct from a star because of its comparative nearness to us. When the heavens are illuminated by this glorious orb, the light which it sheds in every direction is of such dazzling splendour that the feebler rays from the other stars are extinguished in comparison, though many of them are probably larger, but are at such prodigious distances that the light which we receive from them is insignificant. For instance: though we receive ten thousand million times more light from the sun than from a bright star called *α* Lyrae, this star is more than a million times further from us!

This beneficent source of all our light and heat is very different in its nature from the earth. Not only is it of grander proportions, but in a far different physical condition from that of our planet. We have seen that the earth is a spherical body with a circumference of under 25,000 miles, possessing a solid crust, though more or less liquid in parts of its interior; that it is surrounded by an atmosphere containing chiefly nitrogen and oxygen ; and is of diminishing density as we travel outwards from its centre. The sun, though it is composed of intensely hot vapours and gases, also diminishes in density from the centre outwards. The elements of which it is composed are now all known to take part in the composition of the earth. But it was only in the year 1895 that one of them, which was long ago recognised in the sun by Sir Norman Lockyer and called by him helium, was discovered in a comparatively rare mineral, cleveite, by Prof. Ramsay.

Dimensions of the Sun.—From the nature of the materials constituting the sun the student would expect to find that its density is very much less than that of the earth. While the volume of the sun is one and a quarter million times as great as that of the earth, that is, this number of earths would be necessary to build up a globe as large as the sun, its mass is only something over three hundred thousand times as great. But the definition of density is the relation of a body's mass to its volume, and consequently we get the proportion :—

$$\begin{matrix}\text{Earth's}\\\text{density}\end{matrix} : \begin{matrix}\text{sun's}\\\text{density}\end{matrix} = 1 : \frac{300{,}000}{1\frac{1}{4}\ \text{million}} = 1 : \tfrac{1}{4}\ \text{roughly.}$$

The sun's density is, therefore, only one quarter that of the earth, which, as we have seen, is 5·6 times that of water, and thus we get the value 1·4 as the density of the sun. This means that the sun is about one and a half times as heavy as it would be if it were composed of water, or about the same weight as a globe of the same size made of coal would be, for the density of coal is just about 1·4. The diameter of the sun is about 866,000 miles, or about 108 times greater than the earth's diameter, which is very nearly 8,000 miles. It must be clearly understood that this refers only to the relative *diameters*. The area of the sun's disc compared with that of the earth will be the square of 108, *i.e.*, 108 × 108 ; and, similarly, the proportion of their volumes is 1 to the cube of 108, *i.e.*, 108 × 108 × 108. Statistics referring to the sun are given at the end of this chapter, and we only propose now to describe the chief phenomena observable upon the sun.

Methods of observing the Sun's Surface.—Owing to the intensity of its radiations it is dangerous to look at the sun through a telescope without using some means to modify its beams. A dark glass placed over the eye-piece of the telescope is sufficient for a small instrument; but larger telescopes are provided with special solar eye-pieces, so constructed that most of the sun's rays pass through the telescope without reaching the eye, while the remainder is reflected to an eye-piece placed at right angles to the telescope. Another method of observing the solar surface consists in projecting the solar image upon a screen fixed in front of the eye-piece (Fig. 147), and this plan is applicable to either large or small telescopes.

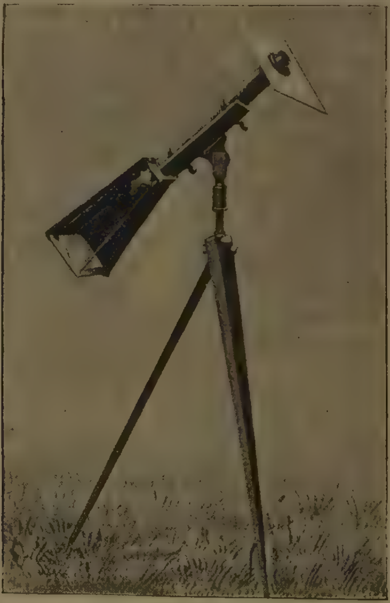

FIG. 147.—Method of observing the Sun. From *Popular Telescopic Astronomy*. By A. Fowler (George Philip and Son).

Still another method is to photograph the sun. The instrument employed for this purpose is a small telescope with a field-glass of about 5 inches in diameter; and since the image of the sun given by such a telescope is very diminutive, an enlarging lens is fixed in the place of the eye-piece, which magnifies the image of the sun's disc up to a diameter of about 2 feet. The exposure required to produce a picture is but a small fraction of a second.

The Sun's Surface.[1]—The visible surface of the sun—"the photosphere," to give its name—is darker near the edges than at the centre. A close investigation of the photosphere shows that it has a texture—a mottled appearance—very similar to that of mottled cardboard (Fig. 148). The marks go by the name of "nodules" or "rice-grains," and though they are minute objects on the sun, the smallest are as large as Great Britain. In

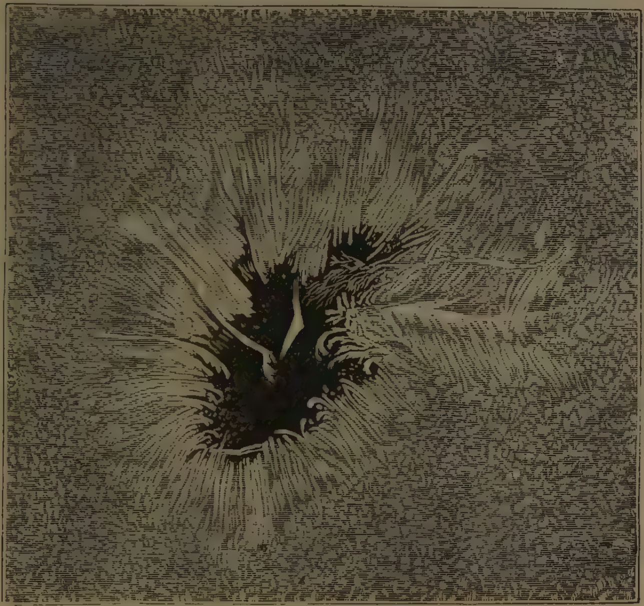

Fig. 148.—Sun Spot and structure of the photosphere round it, as seen by Mr. S. P. Langley.

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[1] The student should read *The Vault of Heaven*, by R. A. Gregory (Methuen and Co.), to which book we have frequently referred.

places the rice-grains are seen to be lengthened so as to have the form of "willow leaves." When the rice-grains are observed under perfect conditions they are seen to be themselves made up of smaller luminous points known as "granules." Prof. Langley has examined the minute structure of the solar photosphere and depicted it with marvellous accuracy. The following remarks of his are therefore of great interest. Describing the appearance presented by the solar surface in telescopes of moderate size, he says:—"We see a disc of nearly uniform brightness, which is yet sensibly darker near the circumference than at the centre. Usually seen relieved against this grey and near the edges are elongated and irregular white patches, faculæ, and at certain epochs trains of spots are scattered across the disc in two principal zones equidistant from the solar equator. On attentive examination it is further seen that the surface of the sun everywhere—even near the centre and where commonly neither faculæ nor spots are visible—it is not absolutely uniform, but is made up of fleecy clouds, whose outlines are all but indistinguishable. The appearance of snow-flakes which have fallen sparsely upon a white cloth partly renders the impression, but no strictly adequate comparison can perhaps be

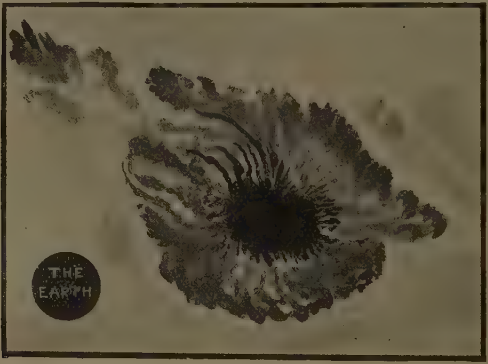

FIG. 149.—Sun Spot observed in August, 1897, compared with the size of the Earth.

found, as under most painstaking scrutiny we discern numerous faint dots on the white ground, which seems to aid in producing the impression of a moss-like structure in the clouds still more delicate, and whose intricate outlines tease the eye, which can neither definitely follow them nor analyse the source of its impression of their existence."

Not only does a telescopic examination reveal this granulation of the sun's surface and the existence of faculæ, but often also of dark spots, formed of a dark centre (umbra) surrounded by a distinctly marked penumbra. These spots appear to move from the eastern edge of the sun to the western, and to change their aspects *concurrently*, that is to say, they are foreshortened when near the edge and are seen "full-face" when near the centre of the disc (Fig. 150).

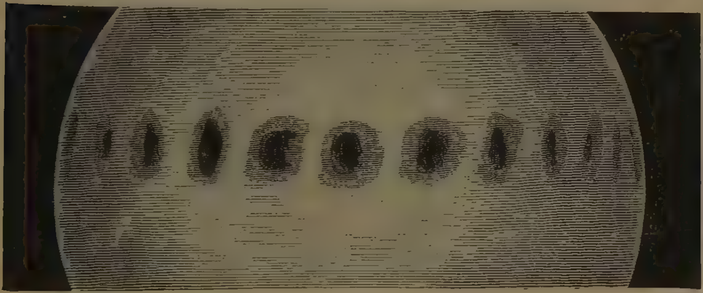

FIG. 150.—Changes in the Aspect of a normal Sun spot as it crosses the Sun's Disc, showing the Spot to be a hollow in the Photosphere.

EXPT. 39.—Paint the centre of the concave surface of a saucer black and the remainder grey. Hold the saucer with the painted face towards the class, and illustrate the different appearances presented by sun spots by letting the class view it at different inclinations.

The simultaneous change of form and position leads to the conclusion that sun spots are cavities in the photosphere, and the different shades of a spot represent different depths. In a few cases spots have been seen as very slight notches when passing over the sun's edge and have even been photographed in this form.

Rotation of the Sun.—The spots which have just been described pass across the sun from its eastern to its western edge, and their mean rate of motion is such that they go completely round the sun in 27·3 days. It is in this way proved by observation of its spots that the sun rotates uniformly, and in the same direction as the planets. The true period of this solar rotation, correcting for the movement of the earth, is 25 days 4 hours 29 minutes. This would consequently be the mean time of rotation of the spots, as measured by one of our astronomers, if the earth were fixed and it were possible for him to observe them from a fixed observatory. The rate at which sun spots travel, or, what is the same thing, the rate of the sun's rotation, is not the same for all solar latitudes, but diminishes from the equator to the poles. Thus, if 25 days is taken as the time of rotation deduced from observations of spots near the sun's equator, that calculated from measurements of spots in solar latitude 20° would be 25·75 days. Similarly, from those in latitude 30°, we should obtain 26·5 days, and in latitude 40°, 27 days. The decrease of rate appears to continue polewards, but it cannot be determined by observations of spots, as few have been seen in latitudes higher than 40° N. or S., but from measurements in connection with faculæ, which appear in high as well as low latitudes.

There is still another plan for determining the velocity of the sun's rotation, based upon what is known as Doppler's principle. It is a well-known fact in Physics that the pitch of a musical note emitted from a moving source of sound is either lowered or heightened according as to whether the sounding body is receding from or approaching the observer. Similarly, the pitch or colour of a light wave, which, as the student knows, depends upon the wave length of the radiation, is correspondingly lowered or heightened under identical circumstances. By such considerations, with the help of an instrument called the *spectroscope* (p. 428), it has been found possible to make direct determinations of the velocity at the eastern and western edges of the sun in different latitudes, and so establish the fact of, and measure the rate of, the sun's rotation.

The Sun's Axis.—The line on which the rotation of the sun, which has now been explained, may be presumed to take place, is what we mean by its axis. This axis is not at right angles to the plane of the ecliptic, for if it were, the spots in their passage across the sun's disc would trace out lines parallel to the ecliptic, and they do not. What is really noticed depends upon the time of the year at which observations are made. In June and December the spots travel along straight lines, which are, however, inclined to the ecliptic ; in the former month the spots move downwards as they travel across the disc, while in the latter upwards. In March and September the paths of the spots are curved ; in the former case the convexity of the path is towards the solar north pole, and in the latter towards its south pole. (Fig. 151).

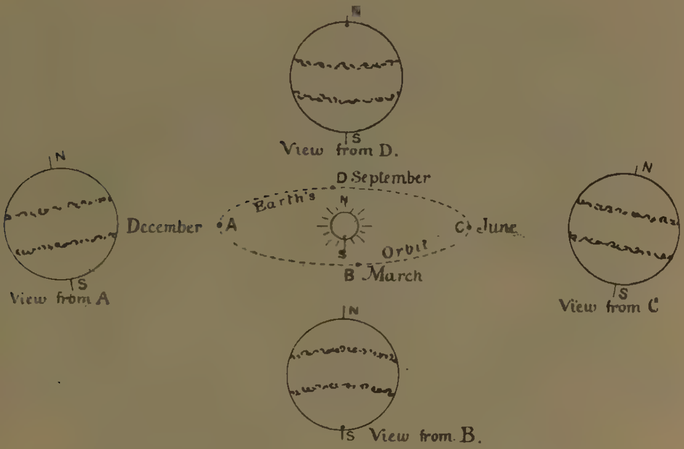

FIG. 151.—To illustrate the inclination of the Sun's axis, and the resulting differences of apparent paths of Sun spots at different times of the year. The way in which spots appear to travel when viewed from the points A, B, C, D, of the orbit are shown in the outer figures.

These phenomena can only be explained by the assumption of the inclination of the sun's axis to the plane of the ecliptic. Moreover, the north pole of the sun must, to explain what we have described, be tilted towards that part of its orbit at which the earth arrives in September each year, and consequently its south pole be directed towards the part occupied by the earth in March. In December and June the earth is in exactly intermediate positions on its orbit, and the sun's axis is viewed sideways, neither its north nor south pole being tilted towards the points occupied by the earth in those months.

The Solar Corona.—The student has learnt from his elementary book[1] why, at certain intervals of time, the moon eclipses the sun. When this happens we are able to see solar phenomena invisible to the unaided eye at ordinary times. The brilliant light of the photosphere is shut off by the dark body of the moon, and an irregular faintly luminous envelope surrounding the sun and extending to tremendous distances into space, becomes visible. This is the *solar corona.* It undoubtedly belongs to the sun, but cannot be seen when the sun is brightly shining, under normal circumstances, because its light is scattered by the earth's atmosphere, just as is the light of the stars. A photograph obtained during the eclipse of 1889 is reproduced in Fig. 152.

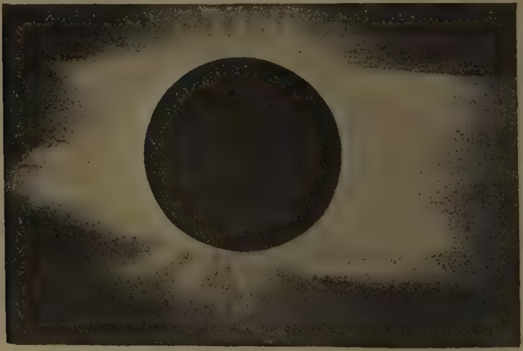

FIG. 152.—The Solar Corona observed and photographed during a total Solar eclipse in 1889.

The Chromosphere and Prominences.—A number of scarlet-tinted flames or prominences are seen projecting from behind the moon's edge during a total solar eclipse. These also come from the sun, and are clouds of luminous gas rising above a turbulent stratum—the *chromosphere*—which overlies the photosphere. They are invisible upon ordinary occasions for the same reason that the corona and stars are invisible in the daytime. It may seem curious that the chromosphere and the prominences—which are merely elevated parts of it—should overlie the ordinary visible surface of the sun and yet be invisible. The reason is that the light is not nearly so intense as the bright light of the photosphere, which overcomes and drowns their distinctive luminosity. It may be mentioned, however, that, thanks to a method discovered independently by Mr. (now Sir Norman) Lockyer and Prof. Janssen in 1868, it is possible to observe the prominences by means of a spectroscope without waiting for a total eclipse of the sun. Every day, when the sun is shining, in observatories devoted to the study of solar phenomena, solar prominences are observed. They often shoot up for tens or even thousands of miles above the chromosphere, with velocities up to 200 miles per second. The development of a solar prominence observed by means of a spectroscope by Father Fényi on December 24, 1894, is shown in Fig. 153.

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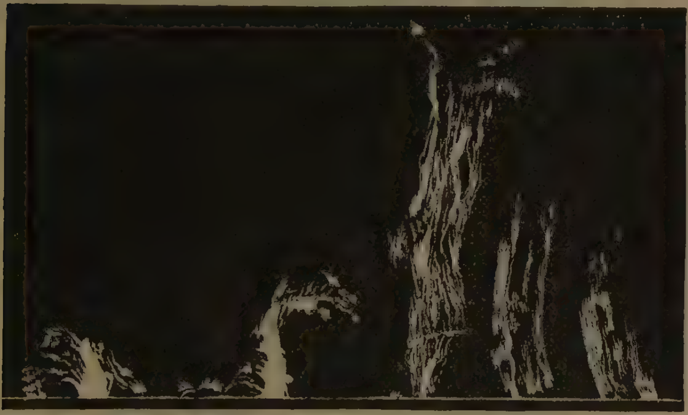
[1] *Physiography for Beginners*, pp. 193, 194.



10h. 15m. 11h. 55m. 12h. 38m.

FIG. 153—Rise and fall of a Solar Prominence in 2h. 23m. Greatest height 661″, that is, 297,450 miles.

Variations of Solar Activity.—The surface of the sun is in incessant commotion, particularly in certain regions: the spots, for instance, show a preference for two zones between 10° and 35°, heliocentric latitude (N. and S.). This activity, which is general over the whole disc, is evidenced during a total eclipse behind the dark edge of the obscuring moon as brilliant jets and flames, already referred to as prominences.

These prominences mainly consist of hydrogen and helium, and arise out of that solar envelope, called the chromosphere, which overlies the photosphere. Outside the chromosphere again is the corona or coronal atmosphere, extending in sheets and streamers of extremely attenuated and luminous material to distances often many times greater than the sun's diameter.

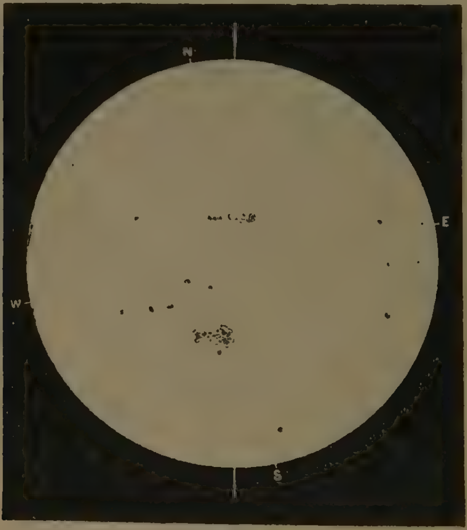


FIG. 154.—The Spots on the Sun on August 7, 1893, when Solar activity was at a maximum. From *L'Astronomie.*

The degree of activity of the solar surface is periodically variable; the magnitude and number of spots, faculæ, and prominences, pass from a maximum to a minimum, and from this minimum to a maximum again. The period of variation occupies a little over eleven years. The most recent maximum occurred in 1893 or 1894 (Fig. 154), and the last minimum in 1889. These fluctuations appear to be directly related to variations of terrestrial magnetism, and the frequency of auroræ (see p. 465).

Constitution of the Sun.—Opinions differ both as to the constitution of the sun and the causes which produce solar phenomena. Prof. C. A. Young,[1] one of the foremost living authorities upon the subject, sums up the generally received opinions in words which we reproduce with a few trifling alterations :—

The central mass, or *nucleus* of the sun, is probably *gaseous* though under enormous pressure and at an enormous temperature.

The *photosphere* is probably a sheet of *luminous clouds*, constituted mechanically like terrestrial clouds, *i.e.*, of small, solid or liquid particles floating in gas. These photospheric clouds float in an atmosphere composed of these gases which do not condense into solid or liquid particles at the temperature of the solar surface. This atmosphere is ladened, of course, with the vapours out of which the clouds have been condensed.

The *chromosphere and prominences* appear to be constituted of permanent gases, mainly hydrogen and helium, which are mingled with the vapours in the region of the photosphere, but rise to far greater elevations. For the most part the prominences appear to be formed by jets of hydrogen, etc., ascending through the interstices between the photospheric clouds, like flames playing over a coal fire.

As to the *corona*, it is as yet impossible to give any satisfactory explanation of all the phenomena that it presents ; and since, thus far, it has only been possible to observe it during the brief moments of total eclipses, progress in its study has been necessarily slow.

Sun Spots are unquestionably cavities or hollows in the photosphere. They are filled with gases and vapours which are cooler than the surrounding regions, and therefore absorb a considerable portion of the light and make the spot look dark.

Faculæ are masses of the same material as the rest of the photosphere, but elevated above the general level, and consequently intensified in brightness.

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[1] *Lessons in Astronomy.* By Prof. C. A. Young. Ginn and Co. 6*s.*

THE MOON.

General Statement.—The path on which the moon revolves round the earth is, like that on which the earth travels round the sun, of an elliptical form. The proof that the moon's orbit is an ellipse is afforded by measurements of the lunar diameter throughout the month. The diameter is found to vary, being of course greatest when the moon is nearest to us.

The moon's diameter is about 2,163 miles, or a little more than one quarter that of the earth's diameter. While the earth is eighty times heavier than the moon, it is only about fifty times as large; hence, bulk for bulk, the earth is heavier than the moon in very nearly the proportion of eight to five. Its density compared with water is 3·4; that compared with the earth is found immediately from the definition of density—

$$\begin{aligned}\text{Density} &= \frac{\text{mass}}{\text{volume}}\\ &= \tfrac{1}{80} \div \tfrac{1}{49}\\ &= \tfrac{49}{80} = 0{\cdot}613.\end{aligned}$$

The moon rotates once on its axis in the same time that it completes a single revolution round the earth, and, as a necessary consequence, practically the same lunar surface is always presented to us. The phases, or changes in the moon's aspect, occur because our satellite is an opaque body, and shines only by reflected sunlight. One hemisphere is, therefore, always dark and the other light, and only that part of the illuminated half turned towards the earth at any time can be seen.

Physical Features of the Moon.—The darker parts of the illuminated surface of the moon, as seen by the naked eye or with a small telescope, were considered by observers of two or three hundred years ago to be seas, while they took the bright parts to be land. But the so-called seas, when examined by telescopes of 3 or 4 inches in diameter, appear to be broken up by various streaks and peaks, and do not exhibit continuous surfaces such as they would do if they consisted of water.

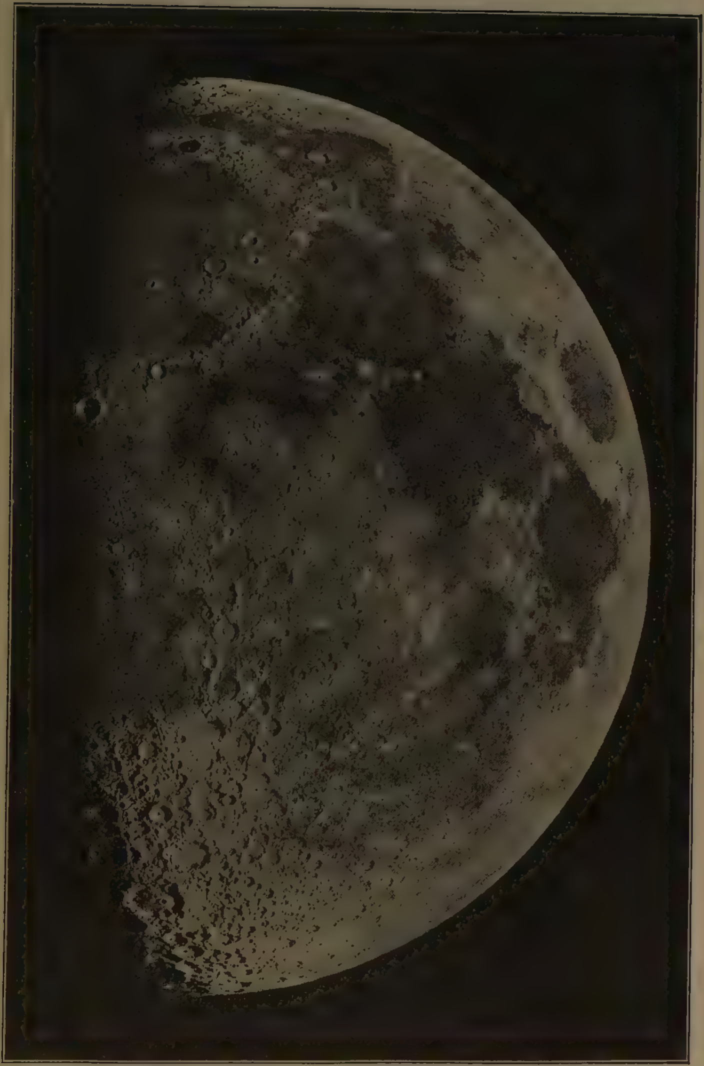

FIG. 155.—The Moon. Reproduced from a Photograph taken at the Paris Observatory.

Lunar formations may be grouped into five classes :—

1. *Craters* more or less like the mouths of terrestrial volcanoes in appearance.

2. *Plains*, which are the seas of early astronomers.

3. *Mountain formations* similar to mountain ranges on the earth.

4. *Rills and clefts*, often running like deep trenches for many miles through plains and mountains.

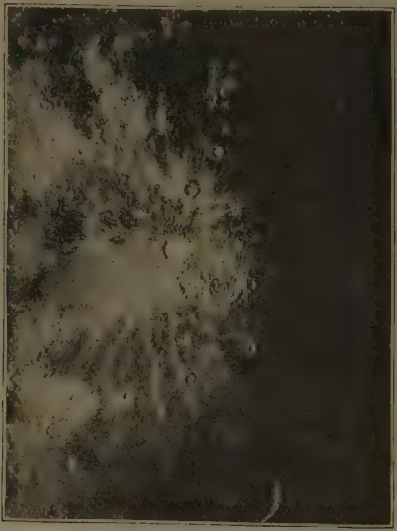

FIG. 156.—The Lunar Crater Copernicus, and the bright Streaks radiating from it. (From a Photograph taken at the Paris Observatory.)

5. *Ray-systems*, or bright-coloured streaks, which spread out from some of the craters, and give much the same appearance as a peeled orange.

All these formations can be traced in the beautiful photograph reproduced in Fig. 155. One of the ray-systems—that which belongs to the crater Copernicus—is shown in Fig. 156.

Lunar Craters.—These craters vary in size between very wide limits. Some are so small that they can scarcely be distinguished, even with a large telescope; while others have diameters of as much as fifty, or in some few cases a hundred miles. Each consists of a circular rampart, or ring of rock, rising to a considerable height above the level of the surrounding lunar country, and generally one or more conical peaks are to be found within the enclosed area. Lunar craters are thus very large compared with terrestrial ones.

We can only speculate as to the mode of origin of the craters. They resemble those which occur on the earth so closely that one naturally regards them as the products of similar forces. It must, however, be borne in mind that volcanic forces on the moon of the same intensity as those experienced on our earth would there throw materials to much greater distances, on account of the circumstance that the stress of gravity on the moon is only one-sixth as strong as it is on the earth. Opposed to the volcanic theory, however, we have the evidence that no water exists upon the moon; and volcanic action, as we understand it, is inconceivable in the absence of water.

The Moon has no Atmosphere.—If there were water on the moon there would necessarily be an atmosphere of water vapour. The absence of any sort of appreciable atmosphere is indicated by the following observations:—

1. The well-defined character of all shadows upon the lunar surface. They are invariably free from blurred edges.

2. The *sudden* disappearance of a star when the moon comes between it and the earth.

3 The edge of the moon is as bright and sharp as other parts of its disc; whereas, if there were a lunar atmosphere, it would be dim and hazy.

Temperature of the Moon.—Every place upon the moon is illuminated for fourteen days, and in darkness for the same period. During this "fortnightly" day the sun's rays tend to make the rocks of the lunar surface very hot; but, on account of the absence of an atmosphere, the heat is radiated into space almost as fast as it is received. Even during this long day the temperature of the sun-lit portion of the moon is probably not higher than the freezing point of water, and during the fourteen days of darkness it must fall two or three hundred degrees below zero.

Solar Statistics.[1]

Solar parallax (equatorial horizontal), 8″·80 (0″·02).

Mean distance of the sun from the earth, 92,885,000 miles (149,480,000 kilos).

Variation of the distance of the sun from the earth between January and June, 3,100,000 miles (4,950,000 kilos).

Linear value of 1″ on the sun's surface, 4,503 miles (7,247 kilos.).

Mean angular semidiameter of the sun, 16′ 2″·0.

Sun's linear diameter, 866,400 miles (1,394,300 kilos.).

(This may, perhaps, be *variable* to the extent of several hundred miles.)

Ratio of the sun's diameter to the earth's, 109·3.

Surface of the sun compared with the earth, 11,940.

Volume, or cubic contents of the sun, compared with the earth, 1,305,000.

Mass, or quantity of matter of the sun, compared with the earth, 330,000 ± 3,000.

Mean density of the sun compared with the earth, 0·253.

Mean density of the sun compared with water, 1·406.

Force of gravity on the sun's surface compared with that on the earth, 27·6.

Distance a body would fall in one second, 444·4 feet (135·5 metres).

Inclination of the sun's equator to the ecliptic, 7°15′.

Longitude of its ascending node, 74°.

Date when the sun is at the node, June 4—5.

Mean time of the sun's rotation (Carrington), 25·38 days.

Time of rotation of the sun's equator, 25 days.

Time of rotation at latitude 20°, 25·75 days.

Time of rotation at latitude 30°, 26·5 days.

Time of rotation at latitude 45°, 27·5 days.

> (These last four numbers are somewhat doubtful, the formulæ of various authorities giving results differing by several hours in some cases.)

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[1] From *The Sun*. By Prof. C. A. Young. (Kegan Paul and Co.)

Linear velocity of the sun's rotation at his equator, 1,261 miles per second, 2,028 kilometres per second.

Total quantity of sunlight, 1,575,000,000,000,000,000,000,000,000 candles.

Intensity of the sunlight at the surface of the sun, 190,000 times that of a candle flame; 5,300 times that of metal in a Bessemer converter; 146 times that of a calcium light; 3·4 times that of an electric arc.

Brightness of a point on the sun's limb compared with that of a point near the centre of the disc, 25 per cent.

Heat received per minute from the sun upon a square metre perpendicularly exposed to the solar radiation, at the upper surface of the earth's atmosphere (*the solar constant*), 25 calories. Heat radiation at the surface of the sun, per square metre per minute, 1,117,000 calories. Thickness of a shell of ice which would be melted from the surface of the sun per minute, 48½ feet, or 14¾ metres.

Mechanical equivalent of the solar radiation at the sun's surface, continuously acting, 109,000 horse-power per square metre, or 10,000 (nearly) per square foot.

Effective temperature of the solar surface (according to Rossett) about 10,000° C., or 18,000° F.

LUNAR STATISTICS.

Diameter of moon, 2,163 miles, $\frac{1}{3{\cdot}66}$ of the earth.

Surface of moon, 14,657,000 square miles, $\frac{1}{13{\cdot}44}$ of the earth.

Solid contents of the moon, 5,276,000,000 cubic miles, $\frac{1}{49{\cdot}20}$ of the earth.

Mass of moon, 73 million tons, $\frac{1}{81{\cdot}40}$ of the earth.

Density of moon, ⅗ of the earth.
Density of moon compared with water, 3·44.
Force of gravity at the moon's surface, ⅙ of the earth.
Average distance from the earth, 238,840 miles.
Greatest distance from the earth, 252,970 miles.
Least distance from the earth, 221,617 miles.

Length of a lunar month, 29 days, 12 hours, 44 minutes, 2·7 seconds.

Length of a sidereal month, 27 days, 7 hours, 43 minutes, 11·5 seconds.

Area of the moon never seen, 41 per cent.

Area visible at various times, 59 per cent.

Inclination of axis to ecliptic plane, 87° 25′ 51″.

Inclination of orbit to ecliptic plane, 5° 8′.

Length of the Saros or eclipse period, 223 months, or 6,585¾ days.

The light of about 6,000,000 full moons would be required to equal the light of the sun.

The temperature of the moon's surface is never above 32° F. and for days together is far below it.

CHIEF POINTS OF CHAPTER XV.

Methods of Observing the Sun's Surface.—(*a*) By means of a dark glass or special eye-piece fitted upon a telescope; (*b*) by projecting the sun's image upon a screen; (*c*) by photography.

Sun's Surface.—The *photosphere* is the visible surface of the sun. Granulated or "rice-grain" appearance of the photosphere. The occasional "willow leaf" form of the granulation in the neighbourhood of sun-spots.

Sun-spots.—The dark umbra, and the lighted fringe, or penumbra of sun-spots. Sun-spots are cool cavities in the solar surface; they vary in size and undergo considerable changes during the time they are visible. Zones to which sun spots are almost entirely confined (5° to 35° north and south of the solar equator). Rise and fall in the number and extent of sun-spots in a period of eleven years. Corresponding variation of terrestrial magnetism and in the frequency of the appearance of auroræ.

Faculæ are irregular white patches found at all points of the sun's surface, but best seen near sun-spots or near the sun's edge.

The Sun's Rotation is demonstrated by observations of the change of position of sun-spots from day to day. Period of rotation: about 25 days at solar equator, and increasing to 27 days in solar latitude 40°. Axis of rotation is about 7° out of the perpendicular to the ecliptic, and the north pole of the sun is tilted in the direction of the earth in September.

The Solar Corona, Prominences, and Chromosphere.—The *corona* is a luminous, irregular envelope only observable during total solar eclipses; its constitution is doubtful. *Prominences*, or "red flames," are masses of glowing gas (mostly hydrogen and helium), projected above the general level of a stratum which overlies the photosphere, and is termed the *chromosphere*.

The Moon's Orbit.—The moon travels round the earth in an ellipse, of which the earth occupies one of the foci. The inclination of this orbit to the elliptic varies between 5° and 5° 18′.

Perigee, Apogee.—When the moon is at its nearest point to the earth in the course of its revolution it is said to be in *perigee*; when it is at that point of the orbit most removed from the earth it is said to be in *apogee*.

Physical Features of the Moon.—The extensive dark patches known to early observers as seas and oceans, have been proved by closer telescopic study to be broken up like other parts of the lunar surface, though not to the same extent. The various lunar formations may be classified into (*a*) craters, (*b*) plains, (*c*) mountain ranges, (*d*) rills and clefts, (*e*) rays, or bright coloured streaks.

The Absence of an Appreciable Lunar Atmosphere is indicated by (*a*) the well-defined character of shadows upon the moon, (*b*) the sharpness of the edge of the moon when seen with a telescope, (*c*) the sudden disappearance of a star when the moon comes between it and the earth, (*d*) no clouds are ever seen upon the moon.

Questions on Chapter XV.

(1) What are the facts which lead us to suppose that the moon has no atmosphere?

(2) What are the principal phenomena observed during a total eclipse of the sun?

(3) What has been learnt of the sun's rotation by the observation of spots?

(4) Describe a sunspot and explain the terms, Corona, chromosphere, photosphere.

(5) What is a sunspot and how are the spots distributed over the sun's disc?

(6) What precautions should be taken in using a telescope to observe the sun?

(7) State the mass and volume of the sun in comparison with the earth, and determine the sun's density from the values you give.

(8) Give a clear statement of the argument that the sun's density is about 1·4 times the density of water.

(9) Describe the appearance of the visible surface of the sun when observed through a good telescope.

(10) Describe the telescopic appearance of a normal sunspot, and state how observations of sunspots prove the rotation of the sun.

(11) What peculiarities with regard to the rotation of the sun are brought out by observations of sunspots?

(12) In what time does the sun make a complete rotation? Is the time of rotation the same in all solar latitudes?

(13) How can the direction of the sun's axis be determined by observations of sun spots?

(14) What differences are observed in the apparent paths of spots across the sun at different times of the year?

(15) Describe the solar corona, chromosphere, and prominences. Why do we not see these prominences when the sun is shining at ordinary times?

(16) Describe briefly the physical constitution of the sun.

(17) State the mass and volume of the moon, and show how the density of the moon can be determined from the values you give.

(18) Describe briefly the chief physical features of the lunar surface.

(19) Write a short essay upon the moon.

CHAPTER XVI

THE UNIVERSE

THE TERRESTRIAL PLANETS AND THEIR MOONS.

General Description of the Planets.—We shall now give a short description of the different members of the solar system, beginning with the one nearest the sun.

Mercury.

Mean distance from the sun	36,000,000 miles
Period of revolution in orbit	88 days
Mean diameter	3,030 miles
Period of rotation on axis	88 days [?]
Mass (earth's mass = 1)	0·06
Density (water = 1)	6·45
Surface gravity (gravity at earth's equator = 1)	0·44

SATELLITES.—None.

Mercury in its Orbit.—The smallest and lightest of the great planets, Mercury, is the nearest of them all to the sun. The result of this proximity is that it is very rarely a prominent object of the heavens in these latitudes. Indeed, not many people in the British Isles have seen Mercury. At definite times this planet takes up a position a short distance above the sun, as a *morning star;* and again at other stated periods a little above the sun at its setting as an *evening star*. But in this country the bank of mist which usually lies along the horizon most often effectually obscures the planet from our view, even when it is at its brightest.

Phases of Mercury.—Mercury and also Venus, the other planet between the earth and the sun, exhibit the phenomena of *phases* just as our moon does. There are no points of difference in the causes which give rise to these varying illuminations in the two cases, and the explanation given in the case of Venus (p. 358) also applies to this planet.

Transits of Mercury.—When Mercury in the course of its revolution takes up a position exactly between the earth and the sun it appears to us as a black spot moving across the sun's disc. This constitutes a *transit* of the planet. The cause is very simple. Having no light of its own the side of Mercury nearest the earth is unilluminated, and hence gives rise to the appearance of a black spot on the bright background of the sun's disc.

Physical Features of Mercury.—Different planets are characterised by different markings. Those of Mercury are said to be of a permanent nature but observers differ very widely in their drawings of the planet. Bright spots are occasionally noticed, and are most pronounced near the planet's north pole. These spots are never seen near the edge or *limb* of the planet's disc, a fact which is probably explained by the great density of the Mercurial atmosphere, though there is evidence that this is not as dense as that of the earth. The markings of Mercury appear to be more distinct and better defined than those of Venus. Moreover, since they were seen by Schiaparelli and others in the same place, even after the lapse of several days, it would appear that the planet rotates very slowly. The view accepted by astronomers generally is that this planet rotates once on its axis in the same period that it completes a revolution round the sun, viz., 88 days, in this way behaving like our moon, which rotates once only in revolving round the earth once.

Venus.

Mean distance from the sun	67,200,000 miles
Period of revolution in orbit	225 days
Mean diameter	7,700 miles
Period of rotation on axis	225 days [?]
Mass (earth's mass = 1)	0·78
Density (water = 1)	4·44
Surface gravity (gravity at earth's equator = 1)	0·8

SATELLITES.—None.

Venus in its Orbit.—The other planet besides Mercury which is nearer the sun than the earth is most commonly known as *the* "evening star" or *the* "morning star." When Venus is visible in the sky it is by far the brightest object in the heavens. This, because of its nearness to the sun, will, as in the case of Mercury, be for a few hours before sunrise or a few hours after sunset. Its path among the stars as viewed from the earth has

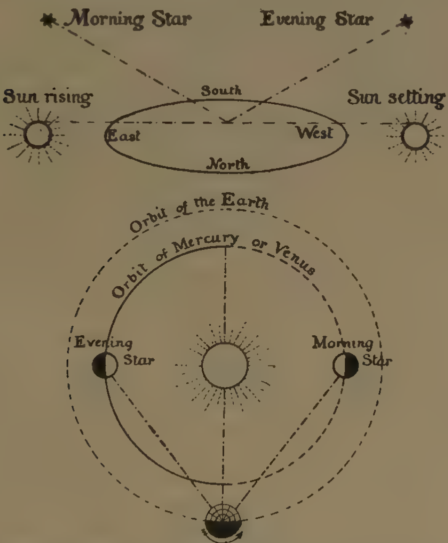

FIG. 157.—The Upper Diagram shows "Morning" and "Evening" Stars with reference to the Sun, as seen by an Observer on the Earth; the lower one shows how "Morning" and "Evening" Stars are caused. In the interior Orbit, the Planet is a Morning Star when on the broken line, and an Evening Star when on the continuous line.

the same general characters as that of Mercury. If it is watched day by day, when it first appears as an evening star, its position seems to steadily change, becoming more and more eastward. After a time this eastward movement ceases and the planet remains stationary for a day or two. Then a westward progression is observed; the planet gets closer and closer to the sun at sunset and is finally lost in the twilight glows. After a while, it appears on the other side of the sun, and is seen as a morning star. It moves to a maximum distance of 47° away from the sun, and then goes back to the sun again.

Venus thus appears to oscillate to and fro between 47° west and 47° east of the sun. Of course, the planet does not really swing to and fro in this way, but only seems to do so on account of her own motion and the earth's motion round the sun.

Morning and Evening Stars.—The appearances of Mercury and Venus before sunrise and after sunset, which have given rise to the popular expressions "morning" and "evening" stars, are easily understood by a reference to Fig. 157. When Mercury or Venus occupies the position in their orbits shown on the right in the lower diagram, the earth, as it rotates, brings an observer into such a position that he sees the planet before the sun becomes visible to him, *i.e.* before sunrise. When, on the other hand, the planet is on the part of the orbit represented on the left side of the figure it is seen after the sun has set, and is therefore an evening star. The planets would be visible near the sun in the daytime if it were not for the overpowering glare of the sun's rays.

Phases of Venus.—The student who has, in his elementary work, understood the explanation of the phases of the moon is in possession of the essential facts in connection with this subject. Galileo, who first observed the phases of Venus, describes his observations in a letter to Kepler. The following extract is from a translation of it by Mr. Carlos :—"At first, then, you must know the planet Venus appeared of a perfectly circular form, accurately so, and bounded by a distinct edge, but very small ; this figure Venus kept until it began to approach its greatest distance from the sun, and meanwhile the apparent size of its orb kept on increasing. From that time it began to lose its roundness on the eastern side, which was turned away from the sun, and in a few days it contracted its visible portion into an exact semicircle ; that figure lasted without the smallest alteration until it began to turn towards the sun. . . . At this time it loses the semicircular form more and more, and keeps on diminishing that figure until its conjunction, when it will wane to a very thin crescent. After completing its passage past the sun it will appear to us, at its appearance as a morning star, as only sickle-shaped, turning a very thin crescent away from the sun; afterwards the crescent will fill up more and more until the planet reaches its greatest distance from the sun, in which position it will appear semicircular, and that figure will last for many days without appreciable variation. Then by degrees, from being semicircular it will change to a full orb, and will keep that perfectly circular figure for several months; but at this instant the diameter of the orb of Venus is about five times as large as that which it showed at its first appearance as an evening star."

The appearances described in the above quotation are shown in Fig. 158. The same facts are true of the planet Mercury, and consequently the illustration applies to both planets.

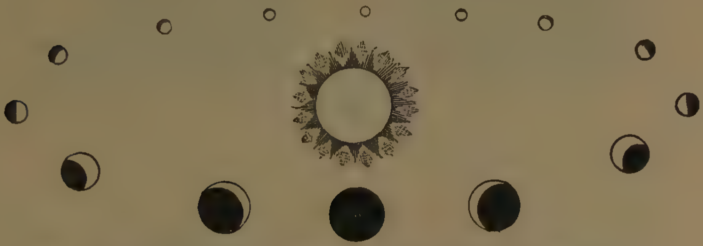

FIG. 158.—Phases of Venus, showing apparent figure and magnitude of the bright and dark portions of the Planet in various parts of the Orbit.

Transits of Venus.—Just as in the case of Mercury the planet Venus is sometimes exactly between the earth and the sun. Under these circumstances the planet appears as a dark spot, which slowly travels across the sun's disc. The *transits* of Venus have been observed by astronomers, and are regarded as events of paramount importance, for by their means the very important question of the distance of the sun from the earth can be determined, in the way described in Chap. XX.

Physical Features of Venus.—The markings upon the surface of Venus are very indistinct. White patches, believed to be snow or ice, have been observed around the poles, and dusky areas of various shapes have been seen by different observers. The general character of these markings is shown in Fig. 159.

The period of rotation of Venus has not been determined satisfactorily, on account of the indistinctness of the surface markings. Until 1890 Venus was generally believed to rotate in about the same time as the earth. But Schiaparelli then discussed the whole of the existing observations, and from these, together with certain others that he added, he arrived at the conclusion that the rotation takes place in 225 days, which is also the period in which the planet revolves round the sun. But astronomers are still divided upon the question of the period of rotation—some of them favour 24 hours, and others 225 days! Venus has an atmosphere, and a very dense one, so that possibly the planet's real surface is entirely obscured by it, and what astronomers see through their telescopes are merely atmospheric phenomena. The axis of Venus appears to be nearly perpendicular to the plane of its orbit.

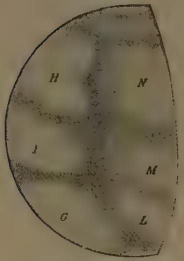

FIG. 159—The Planet Venus, as observed on October 13, 1893.

The Earth.

Mean distance from the sun	92,796,900 miles
Period of revolution in orbit	365·256 days
Mean diameter	7,918 miles
Period of rotation on axis	23h. 56m. 4s.
Mass (sun's mass = 1)	$\frac{1}{327{,}214}$
Density (water = 1)	5·57
Acceleration due to gravity	32·2 ft. per sec.

SATELLITE—THE MOON.

Mean distance from the earth . . .	238,840 miles
Period of revolution	27d. 7h. 43m. 11s.
Diameter	2,163 miles

The Earth as a Member of the Solar System.—Considered as a member of the solar system the earth has no very striking characteristics, nor does it attain the superlative degree in any astronomical feature. It is neither the lightest nor the heaviest, neither the smallest nor the largest, neither the nearest to the sun nor the most remote—of the sun's family. An imaginary observer upon another planet might be able to determine the time of rotation of our world by finding when distinctive markings presented themselves, just as we determine the rotation periods of other planets. But our cloudy atmosphere would often obscure the permanent features of our land and water surfaces. The appearance which the earth would possibly present to an extra-terrestrial observer is shown in Fig. 160, which has been constructed by M. L. T. de Bort,[1] from a knowledge ot atmospheric circulation.

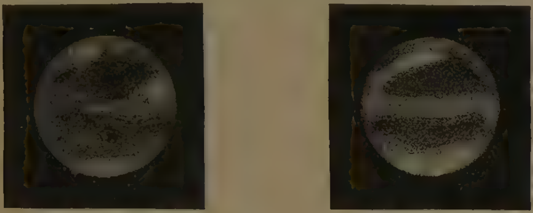
The Old World The Pacific Ocean

FIG. 160.—The Earth with its covering of Cloud, as it would possibly be seen from another planet. (From a Memoir by L. T. de Bort.)

The earth's satellite—the moon—is remarkable in the fact that its size more nearly approaches that of its primary than is the case with any other satellite. The largest satellite in the solar system belongs to Jupiter, and has a diameter of 3,500 miles, which is about one-twenty-fifth that of its primary. The moon, however, has a diameter of 2,160 miles, which is more than one-fourth as great as the diameter of the earth.

The value of the Attraction of Gravity at the Surfaces of other Planets.—The force with which a body upon the surface of a planet is attracted by it depends, as Newton's law of gravitation tells us, upon the mass of the planet and its radius (p. 321) being directly proportional to the former and inversely proportional to the square of the latter, *i.e.* :—

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[1] Report on the Present State of our knowledge respecting the general circulation of the Atmosphere. (*Chicago Meteorological Congress*, 1893.)

$$\text{Surface gravity} = \frac{\text{mass}}{\text{radius}^2}.$$

The attraction of gravity upon a body at the surface of any member of the solar system can thus be compared with the attraction at the earth's surface by dividing such a planet's mass (expressed in terms of the earth's mass as a unit) by the square of its radius (expressed in terms of the earth's radius as a unit). For instance, to find the value of the attraction of gravity at the surface of Jupiter, taking the attraction at the earth's surface as unity, we have,

$$\text{Surface gravity for Jupiter} = \frac{\text{mass}}{\text{radius}^2} = \frac{316}{11^2} = 2·6.$$

Consequently a mass whose weight as given by a spring balance at the earth's surface was 1 lb. would indicate a weight of 2·6 lbs., if the spring balance were transferred to Jupiter.

Mars.

Mean distance from the sun	141,500,000 miles
Period of revolution in orbit	1·88 years
Mean diameter	4,230 miles
Period of rotation on axis	24h. 37m. 23s.
Mass (earth's mass = 1)	0·10
Density (water = 1)	3·91
Surface gravity (gravity at earth's equator = 1)	0·38

SATELLITES.

Name.	Distance from Mars.	Period of Revolution.	Diameter.
Phobos . .	5,850 miles	0h. 7h. 39m. 15s.	7 miles [?]
Deimos . .	14,650 ,,	1d. 6h. 17m. 54s.	5 ,, [?]

Mars in its Orbit.—Next to the moon the object of the heavens which can be better observed than any other is the planet Mars, which at certain times is distant from us by only the comparatively short distance of 35,000,000 miles. The reason why Mars is sometimes nearer the earth than at other periods will be at once understood from Fig. 161. When the earth and Mars are on the same side of the sun, as at A and B, they are nearest together, and are said to be in "opposition" (p. 316); when, however, the earth is on one side of the sun and Mars is on the other as at A and C, the two planets are at their greatest distance apart, and Mars is said to be in "conjunction" with the sun. Evidently the best time to observe

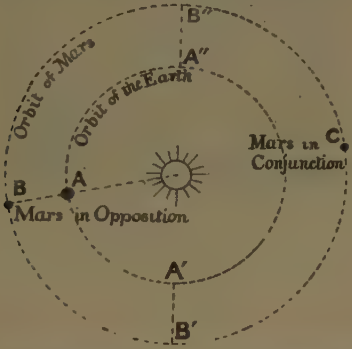


FIG. 161.—To show the positions of Mars at Opposition and Conjunction. Owing to the eccentricity of the Orbit of Mars the distance of the Planet from the Earth is different at different oppositions, *e.g.*, AB, A′B′, A″B″.

Mars is when it is in "opposition," for it is then nearest to us, and is due south in the sky at midnight.

If the orbit of the earth and Mars were concentric circles with the sun at their centres, the distance between the two orbits would be at all parts of them the same. But, as we have pointed out, the orbits are elliptical, and on account of the consequent eccentricity the distance of Mars from the earth differs at different "oppositions." The amount of this difference may amount to 25,000,000 miles. When Mars is at "quadrature" (p. 316) it appears of a *gibbous* (Fig. 162), or cheesecutter shape, —like the moon shortly before full. It cannot, however, exhibit the crescent phases of Mercury and Venus, owing to its greater distance than the earth's from the sun.

Physical Features of Mars.—The planet Mars generally presents the aspect of a ruddy disc, which is, as before remarked, gibbous in form at stated times. Its surface markings can be distinctly made out with a telescope having a four- or five-inch

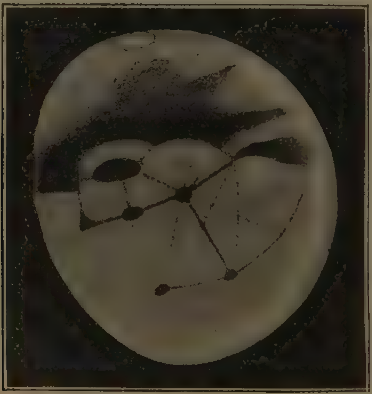
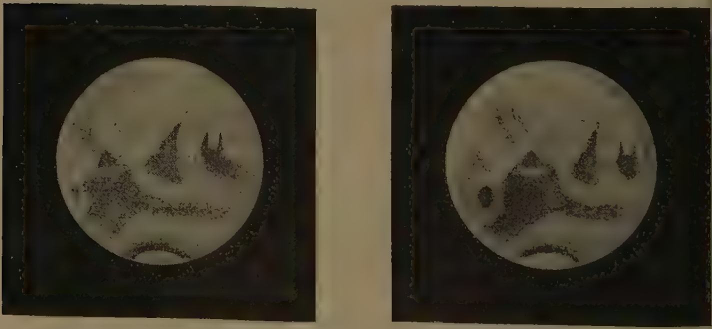


FIG. 162.—Mars on August 29, 1894, showing the Planet in the Gibbous phase. (From a Drawing by Mr. Percival Lowell in *The Astrophysical Journal*, No. 128).



1892, August 17d., 10h. 32m.

1892, August 17d., 11h. 55m.

FIG. 163.—The Planet Mars, as drawn by Prof. James E. Keeler on August 17 1892. The South Polar Cap is shown in each of the Drawings.

field-glass. Their form is practically permanent, and they are rarely obscured by clouds in the planet's atmosphere. These markings are illustrated in Fig. 163 and may be classed under three headings :—

(1) Patches of a greenish colour, which are believed to be of water.

(2) Regions having a ruddy tint, and supposed to be land masses. These reddish portions of the planet's surface are of greater extent than those which are taken to be water areas.

(3) Snow-caps circling the poles. These snow-covered polar regions vary in extent according to the seasons. During the winter they are larger than during the summer ; and, as is true of the earth, the south polar snow-cap is smallest when that of the north pole reaches its greatest size. The decrease and final disappearance of the snow-cap around the south pole in 1894 is shown in Fig. 164.

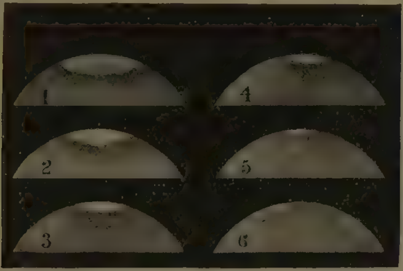


Fig. 164.—Decrease in size of the South Polar Cap of Mars in 1894.
1. May 21 ; 2. June 11 ; 3. July 29 ; 4. August 15 ; 5. October 7 ; 6. November 11.

Canals.—The wonderfully regular markings on the planet's surface, which were first made out by Schiaparelli in 1877, are erroneously called canals in our language. By their discoverer they were termed *canali*, which means more nearly "channels." These channels cross the land surfaces of Mars in every direction, and are, as was shown by the same observer in 1882, in many cases double—two of the channels running parallel for long distances, with a stretch of land of only a few hundred miles between them. Both these sets of observations have since been confirmed by other astronomers. Minute dark spots have often been noticed where two or more of these channels meet. These spots probably represent lakes.

The atmosphere of Mars is almost free from clouds, and, even when they are visible, they are only small and thin. On one or two occasions, however, regions probably greater than the whole of Europe have been obscured by cloud.

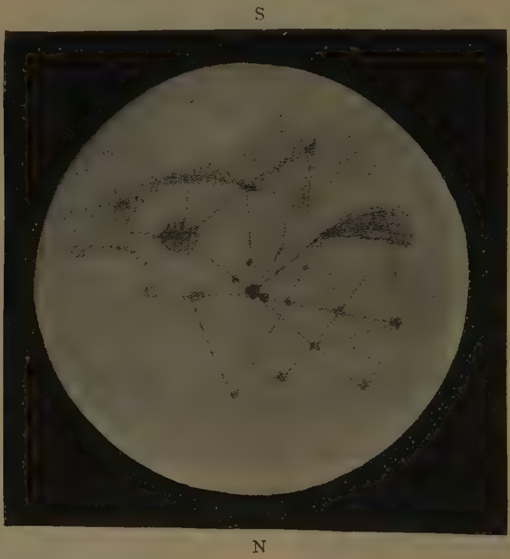


FIG. 165.—View of the Planet Mars, showing Canals, and Lakes where the Canals intersect. From a Drawing by Mr. Percival Lowell. (*The Astrophysical Journal.*)

During the part of its revolution round the sun at which Mars appears gibbous, certain small bright projections have been seen on the edge of the planet's disc, but their nature is not yet understood.

The Satellites of Mars.—The moons of Mars are the two smallest bodies in the solar system, their diameter being only about six miles. They were discovered in 1877, and can only be seen with very large telescopes. The nearest is at a distance of 5,800 miles from the centre of Mars, and therefore less than 4,000 miles from the planet's surface. From this it will be seen that another planet of the same size as Mars, if placed by its side, would reach to the nearest satellite. In the case of our own moon, thirty earths would be required to span the space which separates us from her.

Mars's nearest satellite is made remarkable by the fact that it revolves round its primary in less time than the planet itself rotates; its period of revolution (7h. 39m.) is, in fact, less than one-third the period of rotation of Mars. The inhabitants of Mars (if there be any) therefore possess a moon which rises in the west, and goes through its phases three times a day. This satellite would appear to be of about one-fifth the diameter of our own moon. The second satellite of Mars, being nearly three times further from the planet, would appear like a brilliant star, and would rise in the east and set in the west, like the satellites of other planets.

The Asteroids or Minor Planets.

Number at present (October, 1897) known, 454.
Distances from the sun, 198,000,000 to 400,000,000 miles.
Periods of revolution, 3 years 40 days to 9 years 355 days.
Diameters, 10 miles or so to about 400 miles.
Periods of rotation, unknown.

General Characters.—Between four and five hundred small bodies have been found to be revolving round the sun between the orbits of Mars and Jupiter. These are known as the *minor planets* or *asteroids*, and each of them has a definite orbit of its own. The widespread impression that they all revolve round the sun on one orbit, following one another like trains on a circular railway, is quite erroneous. Their orbits are of various sizes, eccentricities, and inclinations.

The first asteroid was sought and found at the beginning of this century. It was looked for because there were reasons for believing that a planet existed which revolved round the sun at some distance intermediate between Mars and Jupiter. The reason for such a belief arose from the following considerations. If the distance of the earth from the sun be taken as unity, the distances of the other planets can be arranged in a regular series from the nearest to the one most remote. But at the time this law was recognised there was a gap in the series occurring after Mars, indicating the great probability of the existence of a planet between Mars and Jupiter. This started a search for the missing planet. Before long one was discovered, but it turned out to be much smaller than had been anticipated. But since the discovery of the first asteroid until the present time (1897) 454 have been discovered.

Bode's Law.—The fact that *if the distance of the earth from the sun be taken as the unit, the distances of the other planets can be arranged in a regular series from the nearest to the one most remote*, is known as Bode's Law. This discovery can be tabulated thus :—

				Result divided by 10.	Distances of Planets (Earth=1).
Mercury	0	+ 4 =	4	0·4	0·4
Venus	3	+ 4 =	7	0·7	0·7
The Earth . . .	6	+ 4 =	10	1·0	1·0
Mars	12	+ 4 =	16	1·6	1·5
Minor Planets . .	24	+ 4 =	28	2·8	3·0
Jupiter	48	+ 4 =	52	5·2	5·2
Saturn	96	+ 4 =	100	10·0	9·5
Uranus	192	+ 4 =	196	19·6	19·2
Neptune	384	+ 4 =	388	38·8	30·1

The numbers in the first column are each (with the exception of the second one) double the number immediately above it. The addition of four to each number gives the third column. These results divided by 10 are given in the fourth column, and it will be seen that these numbers agree very closely with the actual distances of the planets as shown in the fifth column.

This law was announced in 1772, not only before any minor planets had been observed, but also before the planets Uranus and Neptune had been discovered.

It will be noticed, by referring to the above table, that the planet Neptune is an exception to Bode's law. Its actual distance from the sun is there seen to be 30·1 times greater than the earth's distance, whereas the series makes it 38·8.

Size of the Asteroids.—The four brightest of the minor planets, or asteroids, are Ceres, Pallas, Juno, and Vesta. The diameters of these, according to careful observations made by Prof. E. E. Barnard, are as follows :—

Diameter of Ceres = 485 miles.
" " Pallas = 304 "
" " Juno = 118 "
" " Vesta = 243 "

These dimensions are shown in comparison with the diameter of the moon in Fig. 166. The asteroids we have named are the giants among the minor planets, for the remainder are all of them too small to be measurable. The total mass of the asteroids cannot be as much as one-fourth the mass of the earth, or they would bring about a greater disturbing effect than they do upon Mars and its satellites.

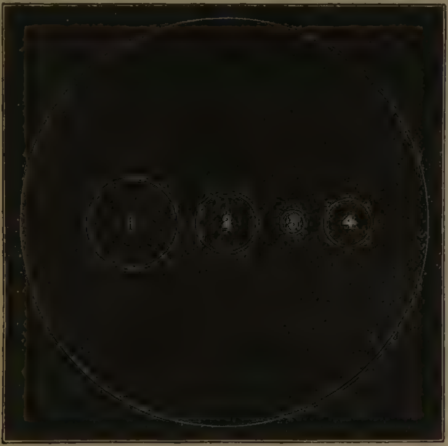


Fig. 166.—Relative Diameters of the four brightest Asteroids and the Moon. Ceres (1), Pallas (2), Juno (3), Vesta (4). The Enclosing circle represents the Moon.

CHIEF POINTS OF CHAPTER XVI.

Mercury is the smallest, lightest, and densest of the great planets, and the nearest planet to the sun. It can only be seen near the sun; it passes through phases like the changes of the moon; and it is sometimes seen in transit as a black spot projected upon the sun. There is no consensus of opinion as to the physical features of the planet, and the time of rotation is doubtful. Mercury has no satellite.

Venus, like Mercury, cannot be well observed on account of its brilliancy and phases, but dusky patches are seen, and sometimes white polar caps. Transits of Venus furnish a means of determining the sun's distance. On account of the indistinctness of the markings, the time of rotation is not accurately known. The axis of rotation is nearly perpendicular to the orbit.

The Earth, the third planet in order of distance from the sun, has a satellite larger in proportion to its own size than the satellite of any other planet. Regarded merely as a member of the solar system the earth is not a very remarkable body.

Mars is in opposition when it, the earth, and the sun are in a straight line, the earth being between the other two. It is then used for the determination of its parallax, and indirectly, to determine the sun's distance. It is in conjunction when it is in a straight line with the earth and sun, but the sun is in the middle. Shows a gibbous phase when at quadrature. Has a low superficial gravity. Chief telescopic features, (*a*) snow caps and their periodic variations in size; (*b*) patches of a greenish shade, believed to be water; (*c*) regions of a yellow tint, supposed to be land. Acute observers see numerous straight lines (canals or channels) crossing the disc in all directions. Rotation period very accurately known. Atmosphere thin and practically cloudless. Satellites two—among the smallest bodies in the solar system.

Bode's Law is a rule to the effect that the distances of the planets from the sun follow a geometrical progression, the earth's distance being taken as unity. Neptune is an exception to the law. Bode's series of numbers indicated that a planet existed at a distance from the sun between the distances of Mars and Jupiter. A planet was looked for to fill up the gap, the result being the discovery of the first asteroid. Number of asteroids now known 454. Only four are above 200 miles in diameter, and the great majority are much smaller.

QUESTIONS ON CHAPTER XVI.

(1) Why is Venus sometimes a morning and sometimes an evening star? State its position with regard to the earth and sun:—

(*a*) At its stationary points.
(*b*) At superior and inferior conjunction.

(2) Describe and explain the phases of Mercury.

(3) What is known about the physical features and time of rotation of Mercury?

(4) Why is it that Mercury can only be seen near the sun?

(5) Show, by means of a diagram, the relative positions of Venus and the earth when Venus is (*a*) a morning star, (*b*) an evening star.

(6) Write down the diameter, period of rotation, and period of revolution of Venus, and describe briefly what is known of the planet's physical features.

(7) Describe the apparent motion of Venus with reference to the sun.

(8) How is it that Venus is never seen more than 47° away from the sun?

(9) Write a short essay on the earth as a member of the solar system.

(10) How would you compare the superficial gravity upon a planet with the force of gravity at the earth's surface, if you knew the mass and diameter of the planet?

(11) When is the best time to observe the planet Mars, and why?

(12) Explain why at some oppositions of Mars the planet is better situated for observation than at others.

(13) Describe the chief classes of markings observed upon the planet Mars by means of a telescope.

(14) Write a short account of the satellites of Mars.

(15) Describe Bode's law, and state how it led to the discovery of the first asteroid.

CHAPTER XVII

THE UNIVERSE

THE MAJOR PLANETS AND THEIR MOONS. COMETS AND METEORITES

Groups of Planets.—The asteroids separate the planets into two groups. The first of these comprises what are called the *terrestrial planets*, viz.: Mercury, Venus, Earth, and Mars. They all more or less resemble one another in size and density, and the Earth may be taken as the type of the group.

The second includes Jupiter, Saturn, Uranus, and Neptune. These are the so-called *major planets*. They are all of them much larger, less dense, and apparently in a less solidified condition than the Earth. Jupiter, the nearest of the major planets, is the largest member of the solar system.

Jupiter.

Mean distance from the sun	483,300,000 miles
Period of revolution in orbit	11·86 years
Mean diameter	86,500 miles
Period of rotation on axis	9 hours 55 minutes
Mass (earth's mass = 1)	309·8
Density (water = 1)	1·33
Surface gravity (gravity at earth's equator = 1)	2·26

SATELLITES.

Name.	Distance from Jupiter.	Period of Revolution.	Diameter.
Not named	112,500 miles	0d. 11h. 58m. 0s.	100 miles [?]
Io	261,000 ,,	1 18 27 33	2450 ,,
Europa	415,000 ,,	3 13 13 42	2045 ,,
Ganymede	664,000 ,,	7 3 42 33	3558 ,,
Callisto	1,167,000 ,,	16 16 32 11	3345 ,,

Physical Features of Jupiter.—As would be anticipated[1] from the small density of this planet and its rapid rotation, of which we shall learn more later, there is a very decided flattening near its poles. This is so marked that it can easily be made out even with a small telescope. Accurate measurements of the dimensions of the planet have shown them to be—

Polar diameter	83,000 miles
Equatorial diameter	88,200 ,,

Irregular dark bands arranged parallel to the planet's equator are always to be seen. They are known as *cloud belts*, and the name most probably correctly expresses their nature. Numerous other markings, various in outline and colour, and like the cloud belts continually changing in the details of their form, are also ever present features of the planet's surface (Fig. 167).

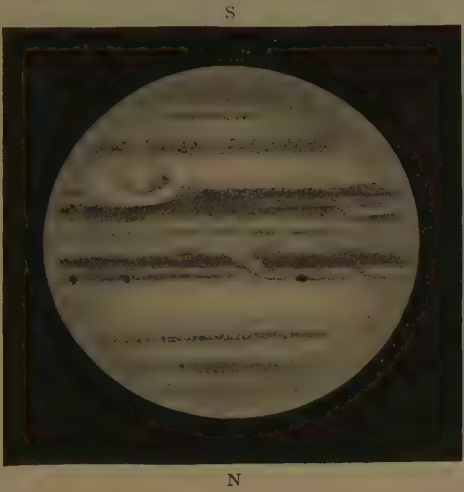


FIG. 167.—The Planet Jupiter, as seen by Prof. Barnard on July 30, 1890.

By observing the motions of spots and other markings on the planet's surface it has been found to rotate once in 9 hours 55 minutes; but the rate of rotation differs at different parts of the planet's surface, being more rapid near the equator than in the neighbourhood of the poles.

For nearly 20 years there has been visible, in the southern hemisphere of Jupiter, a remarkable oval spot. When first observed it was of a brick-red colour, and since that time has gradually become less pronounced in hue, until at present it is scarcely distinguishable from other parts of the surface. This spot has, moreover, slightly increased its rate of rotation to the extent of a few seconds. Of the spot's exact nature nothing is definitely known, but some astronomers have expressed the opinion that it is a break in the planet's atmosphere through which is revealed a part of the actual surface of Jupiter.

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[1] *Physiography for Beginners*, p. 153.

Nature of the Surface of Jupiter.—The markings which have been described are possibly atmospheric phenomena, in which case we may not see anything (with perhaps the above reservation) of the real surface of the planet. Some astronomers do not, however, accept this view.

Prof. E. E. Barnard has given the following as his opinion of the nature of the visible surface of Jupiter:[1]—"After observing the planet for some 12 years I can hardly advocate the theory that the visible surface of Jupiter is a cloud surface.

"It would seem to me more consistent with the observed phenomena to suppose the surface to be in a plastic or pasty condition, the belts and markings being merely discolorations in this, due to internal eruptions. This would easily account for the observed permanence of certain of the markings and for their colours. I do not think the cloud can account at all satisfactorily for the continued permanence of the various markings. The colours and changes of colour are also against it. . . . Possibly one might combine the two theories, and account for any shortcomings in the plastic theory by supposing local clouds of steam near or on the surface."

The Satellites of Jupiter.—Galileo recognised four of Jupiter's satellites as long ago as 1610 revolving round the planet, each on its own orbit, in a manner precisely similar to that in which the moon revolves round the earth. In 1892, 282 years after Galileo's discovery, the astronomical world was startled by the announcement made by Prof. Barnard, then an astronomer at the Lick Observatory, that he had discovered a fifth companion to Jupiter. This satellite revolves round the planet at a distance of 112,400 miles, taking very nearly 12 hours to perform its journey. It is about 150,000 miles nearer the planet than the nearest of the four satellites previously known.

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[1] *Monthly Notices Roy. Astronomical Soc.*, November 1891.

The new satellite is more than 1,500 times fainter than the faintest of the stars visible to the naked eye. The chief reason why it escaped detection for nearly three centuries in spite of the most diligent telescopic research, is that it is almost entirely lost in the glare surrounding the disc of Jupiter.

The orbits of the satellites lie very nearly in the plane of the planet's equator, the result being that one or the other is eclipsed by Jupiter at almost every revolution. These eclipses were utilised by Roemer to determine the time taken by light to travel across the earth's orbit with a view to ascertaining the velocity of light (p. 68). The periods of revolution of Jupiter's satellites are so accurately known and the satellites themselves can be so easily seen, that the times of the eclipses are calculated in advance and used in navigation for the determination of longitude.

The diameters of the four chief satellites are between 2,000 and 3,500 miles, which is not very different from the diameter of our moon (p. 68).

Saturn.

Mean distance from the sun	886,000,000 miles
Period of revolution in orbit	29·46 years
Mean diameter	73,000 miles
Period of rotation on axis	10h. 14m. 24s.
Mass (earth's mass = 1)	92
Density (water = 1)	0·70
Surface gravity (gravity at earth's equator = 1)	1·18

SATELLITES.

Name.	Distance from Saturn.	Period of Revolution.	Diameter.
Mimas . .	117,000 miles	0d. 22h. 37m. 6s.	600 miles
Enceladus	157,000 ,,	1 8 53 7	800 ,,
Tethys . .	186,000 ,,	1 21 18 26	1,100 ,,
Dione . .	238,000 ,,	2 17 41 9	1,200 ,,
Rhea . . .	332,000 ,,	4 12 25 12	1,500 ,,
Titan . . .	771,000 ,,	15 22 41 23	2,720 ,,
Hyperion .	934,000 ,,	21 6 39 27	500 ,,
Japetus . .	2,225,000 ,,	79 7 54 17	2,500 ,,

General Characters of Saturn.—Saturn represents what was to astronomers the limiting planet of the Solar System until a little more than a century ago. It is the least dense of the planets, being actually lighter, bulk for bulk, than water. The degree of polar flattening it exhibits is greater than that of any other member of the sun's family, reaching as it does the large fraction of one-tenth. The actual difference between the two diameters is as much as 7,000 miles. Saturn has a high rate of rotation, the complete spin being effected in 10¼ hours. In this respect it resembles Jupiter as well as in the circumstance that different parts of the surface have different rotational velocities.

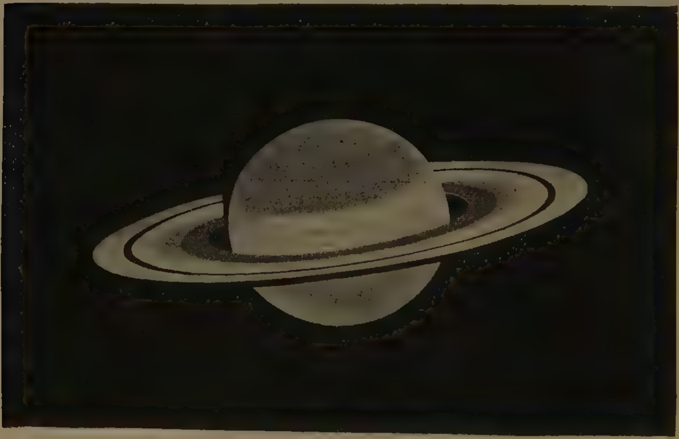


FIG. 168.—The Planet Saturn on July 2, 1894. From a drawing by Prof. G. E. Barnard. (*Monthly Notices of the Royal Astronomical Society*.)

Nor do its resemblances to Jupiter end here. It also possesses belts of cloud which lie parallel to the planet's equator, but they are neither so distinct nor as much given to change of form as the Jovian equivalent. Near Saturn's equator the belt is bright and sometimes faintly tinged with pink; in higher latitudes they are darker in tint, and around a large polar region a cap of a dark greenish tinge is seen. The general appearance of Saturn is shown in Fig. 168.

The Ring System.—The rings of Saturn are unique objects of the Solar System. They are flat and arranged round the planet concentrically and completely encircle it. The rings, which lie in the plane of the planet's equator, are three in number. The outermost is separated from the next broad one, which is the brightest, by a space of 2,300 miles, known as *Cassini's division*, through which stars are sometimes seen. Nearer the planet than this very bright ring is a much fainter semi-transparent one, known as the *crape-ring*, whose inner edge is about 9,000 miles removed from Saturn's surface.

The rings are extremely thin in comparison with their width, and may be compared to a sheet of writing paper surrounding a globe. Their thickness is only about 100 miles, but is not uniform. The dimensions of Saturn and his ring system are given by Prof. Barnard as follows:—

Equatorial diameter of Saturn	76,470 miles
Polar diameter of Saturn	69,770 „
Outer „ „ outer ring	172,310 „
Inner „ „ „ „	150,560 „
Outer „ „ inner „	146,020 „
Inner „ „ „ „	110,200 „
„ „ „ crape „	88,190 „
Width of Cassini division	2,270 „

Phases of Saturn's Rings.—The rings, which are as has been stated located in the planet's equator, are consequently like it inclined at an angle of about 28° to the plane of the ecliptic. In consequence of this, different aspects of the rings are presented to us at different times. Thus, when Saturn is so situated that the plane of the rings passes through the sun the rings are seen edgeways (Fig. 169).

EXPT. 40.—Place a lamp in the centre of a round table, the circumference of which is to represent the earth's orbit. Let the observer move round the edge of the table and so simulate the earth. Get a friend to carry a dinner plate inclined at about 30° to the table round a circle on the floor concentric with the circumference of the table. The plate, which must be held inclined in the same direction throughout its complete revolution, stands for Saturn's rings; and its varying aspects, as seen by the observer, will exactly resemble what the astronomer sees of Saturn's rings through his telescope.

Nature of Saturn's Rings.—Mathematical considerations, and what is known of the strength of materials, are sufficient to prove the impossibility of having a ring composed either of solid or liquid matter of the size of those round Saturn (the outermost has a diameter of 172,310 miles) with the small thickness which they are known to possess. It is fairly certain that the rings are composed of an innumerable host of minute meteoric bodies revolving each on its own orbit round Saturn and sufficiently closely packed to give the impression to terrestrial observers of a continuous whole.

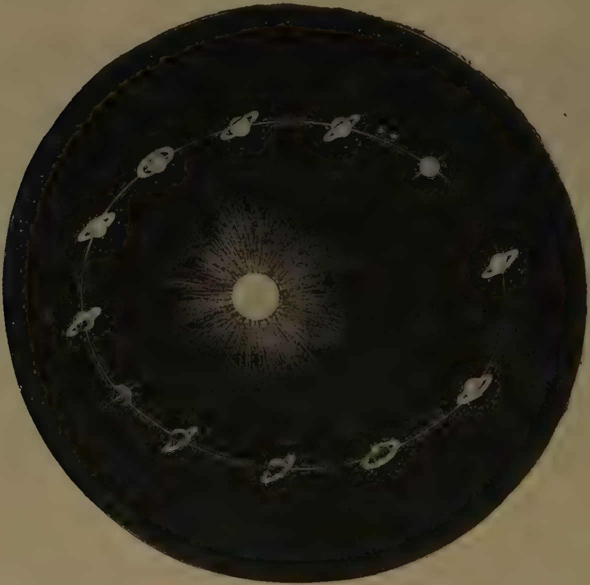


FIG. 169.—Phases of Saturn's Rings, caused by the way in which the light of the Sun strikes the rings in different parts of the Planet's Orbit.

The number of satellites (eight) which Saturn has revolving round it, outside its outermost ring, is larger than in the case of any other planet. The most distant of the eight, which is called Japetus, takes almost as long to revolve once round its primary as Mercury takes to revolve round the sun.

Uranus.

Mean distance from the sun	1,800,000,000 miles
Period of revolution in orbit	84 years
Mean diameter	31,900 miles
Period of rotation on axis	Doubtful
Mass (earth's mass = 1)	13·52
Density (water = 1)	1·07
Surface gravity (gravity at earth's equator = 1)	0·75

SATELLITES.

Name.	Distance from Uranus.	Period of Revolution.	Diameter.
Ariel . . .	120,000 miles	2d. 12h. 29m. 21s.	500 miles
Umbriel .	167,000 ,,	4 3 27 37	400 ,,
Titania . .	273,000 ,,	8 16 56 29	1,000 ,,
Oberon . .	365,000 ,,	13 11 7 6	800 ,,

Uranus and its Satellites.—Uranus was first discovered and recognised as a member of the Solar System by Sir William Herschel in 1781. He originally thought it was a comet (p. 381), but it was not long before its real nature was understood, and its distance from the sun was found to fall in naturally with Bode's series (p. 368).

The markings on Uranus are so indistinct that nothing is definitely known about the planet's period of rotation nor of the direction of the plane of its equator. But since the flattening of the poles can be easily made out, the direction of the axis is known, and is found to be almost at right angles to the plane in which its satellites revolve.

There are four satellites, all comparatively small, revolving on orbits inclined at an angle of 82° to the plane of the ecliptic. Thus, instead of revolving close to the ecliptic plane, as do all the foregoing planets and satellites, they revolve in a plane *nearly perpendicular to the ecliptic*, and, moreover, they revolve *in a retrograde direction*, that is contrary to the direction of revolution of the other members of our system which have previously been described.

Judging from analogy with other planets, the equator of Uranus lies in the plane of the satellites' orbits, so we must conclude that the equator is nearly perpendicular to the ecliptic, while the axis lies almost on the ecliptic.

Neptune.

Mean distance from the sun	2,800,000,000 miles
Period of revolution in orbit	165 years
Mean diameter	34,800 miles
Period of rotation on axis	Doubtful
Mass (earth's mass = 1)	16·47
Density (water = 1)	1·65
Surface gravity (gravity at earth's equator = 1)	1·14

SATELLITE.

Distance from Neptune	225,000 miles
Period of revolution	5d. 21h. 2m. 44s
Diameter	About 2,000 miles

Discovery of Neptune.—It was noticed shortly after its discovery that Uranus did not exactly traverse the orbit, which, by calculations based upon the data then available, it was assumed the planet would. In 1845 the difference between the actual and the computed positions amounted to about two minutes of arc, or one-sixteenth of the average angular diameter of the sun. This minute discrepancy between the observed and calculated positions of Uranus provided two astronomers—Adams and Leverrier—with the data for determining the orbit and mass of a disturbing body which would be sufficient to cause it. But in addition to these numbers about the then hypothetical planet causing the disturbance, these astronomers were able to calculate what the relative positions which the two bodies—the known planet Uranus and the unknown disturbing body—would be at the particular time of the observation on which the mathematical inquiry was based.

The approximate position of the unknown body was thus deduced by both mathematicians. One of them, Leverrier, asked an observer to carefully scan the part of the sky in which the disturbing body ought to be on September 23rd, 1846, and on the same night the body was found near to its calculated position. This new planet was named Neptune. Not only was the discovery a triumph of mathematical astronomy but also gave the strongest evidence of the truth of the law of gravitation in the Solar System, for the successful calculations were based on the assumption of such truth.

Characters of Neptune.—Neptune seems to be devoid of markings upon its surface, at least of markings which can be seen by us, consequently there is no way of determining its period of rotation. It has but one satellite, which completes a revolution round it in a little less than six days, at a distance from it about equal to that of the moon from the earth. The moon of Neptune resembles those of Uranus in having a retrograde motion on its orbit, which is inclined at an angle of nearly 35° to the ecliptic.

Comets.

Introductory.—The popular ideas concerning comets are mostly erroneous. It is usually supposed, for instance, that all comets have tails, a supposition very far indeed from the truth. Many comets, when first recognised through the telescope, merely look like a round patch of mist. Soon a brighter spot, the *nucleus*, develops, and in many cases is situated near the centre of the misty patch. After this a short tail may be seen to form. If the comet is destined to be great, jets of luminous matter spurt out from the nucleus in a direction towards the sun, and are then deflected back to form the tail, which is, in almost every case, pointed away from the sun (Fig. 170). Concentric luminous envelopes also appear on the sunward side of the nucleus, and merge into the tail on the other side. These changes mark the comet's gradual approach to the sun, and are accompanied by a steady increase in size, which continues until a few days after the nearest approach of the comet to the sun, or in other words after it has passed its perihelion point.

Parts of a Comet.—1. The *Coma*, or patch of luminous mist, such as is alone seen when a comet is far away from the sun, and is in its simplest condition. Every comet must, of course, pass through the coma stage, or it would not be a comet.

2. The *nucleus* or bright area which develops, generally near the centre of the coma, and looks like a point of light seen through a fog.

3. The *tail*, or feather-like stream of luminous matter, which many people wrongly regard as the essential part of a comet, since many telescopic comets are without tails.

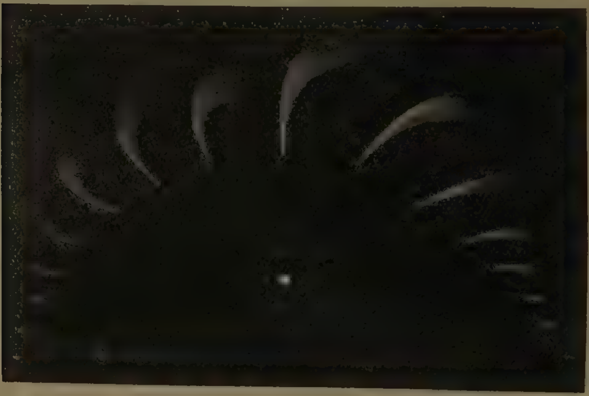


FIG. 170.—To illustrate the increase and decrease in the size of a Comet's tail, when the comet is passing round the Sun. Also the direction of the tail with reference to the Sun.

4. The *jets and envelopes* which shoot out from the nucleus and bend back to form the tail.

Dimensions and Density of Comets.—Comets, which are usually named after their discoverers, are very large bodies. Their heads as a rule are about 50,000 miles in diameter, though sometimes as much as 1,000,000 miles. The tails, too, are generally millions of miles long. But yet the *mass* of a comet is always exceedingly small, not comparable even to that of the relatively insignificant earth. It necessarily follows that the density of a comet, including its tail, must be very small, because while its volume is enormous its mass is trifling.

This very low density is clearly demonstrated by the observation that when the tail of a comet passes between the earth and the stars it neither obliterates them nor refracts the light received by the earth from them.

Motions of Comets.—When an astronomer notices with his telescope a strange patch of mist on the sky, he observes its position with reference to the neighbouring stars, and then watches to see if the object moves, night by night, among them. If it does, he knows that it is a comet; for comets, like planets, move among the stars.

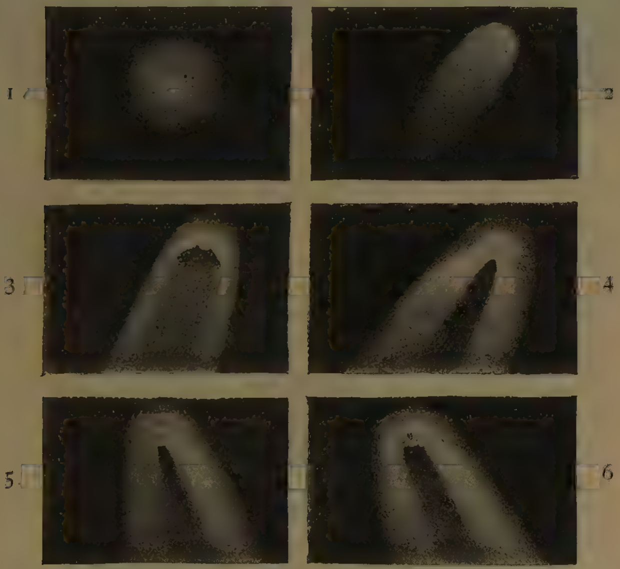


FIG. 171.—To illustrate the changes observed in the head of the Comet of 1858. The development of nucleus, jets, envelopes, and tail is shown.

An object suspected to be a comet can thus be proved to be one or not by applying this criterion of motion. For instance

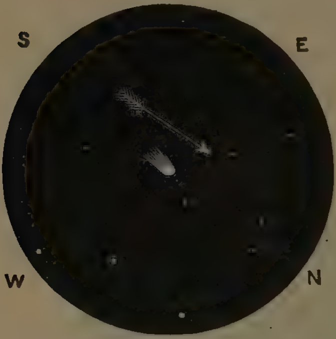


FIG. 172.—Discovery field of Comet. Brooks, 1890, March, 19 d., 16 h.

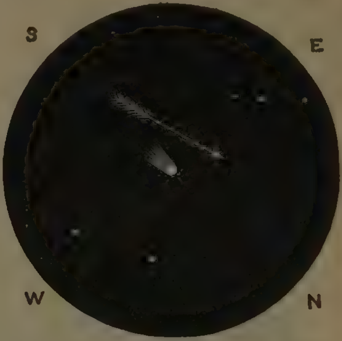
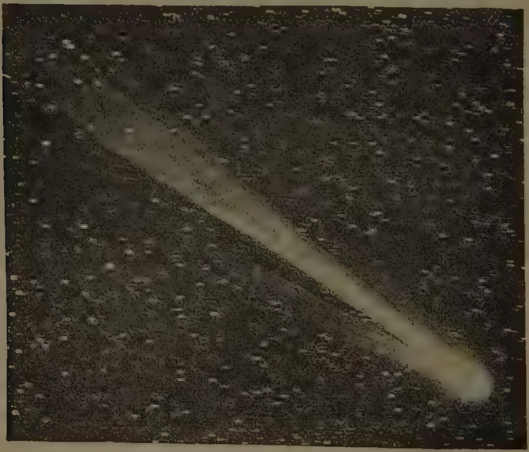


FIG. 173.—Telescopic field of Comet. Brooks, 1890, March, 23 d., 16 h.

(From the *Monthly Notices* of the Royal Astronomical Society.)

a small comet was discovered in 1890 by Mr. W. R. Brooks, and Figs. 172 and 173 show the two drawings he made of it and the



Swift's Comet on April 6, 1892. (From a photograph by Prof. E. E. Barnard.)

FIG. 174.—While the comet was being photographed, it was moving among the stars. The images of the stars are therefore drawn out into short lines, instead of being bright points.

surrounding stars on March 19 and 23, 1890. The comet is clearly shown to have changed its position during the four days which elapsed between the two observations, and the fact of this apparent motion established its cometary nature.

The motion of a comet among the stars is also illustrated by the photograph reproduced in Fig. 174, and by the views of Donati's comet shown in Fig. 180.

Orbits of Comets.—When a small portion of a comet's path has been found in the way just mentioned, the whole orbit can be computed. It has been found that some sixty comets move in orbits of an elliptical form (p. 297), and having varying eccentricities (p. 298). The remaining comets known to astronomers travel along orbits having properties which show that they belong to the classes of curves known to geometricians as *parabolas* and *hyperbolas*. It is desirable that the student should understand something of the differences between these *conic sections* as they are called. A conic section is obtained by the intersection of a cone by a plane. Fig. 175 shows four out of a possible five, which are :—[1]

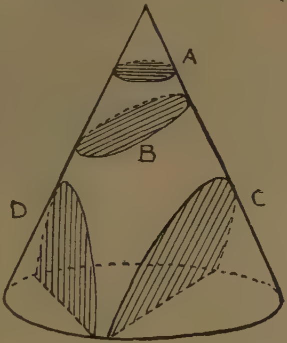


FIG. 175.—Sections of a Cone. From *Science and Art Drawing*, by J. H. Spanton. (Macmillan and Co.)

1. A *triangle*, when the plane cuts the cone through its axis.
2. A *circle*, when the plane cuts the cone parallel to its base as at A, Fig. 175.
3. An *ellipse*, when the plane cuts the cone obliquely, without intersecting the base, as at B, Fig. 175.
4. A *parabola*, when the plane cuts the cone parallel to one side, as at C, Fig. 175.
5. An *hyperbola*, when the cone is cut by a plane that is perpendicular to its base, *i.e.*, parallel to its axis, as at D, or inclined to the axis at a less angle than the side of the cone.

Experiments to show the Forms of Orbits of Comets.—

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[1] See *Science and Art Drawing*. J. Humphrey Spanton. (Macmillan and Co.)

EXPT. 41.[1]—Procure a piece of thin cardboard and cut a circular hole in it as in Fig. 176, and place it a short distance from a lighted candle. A cone of light as shown in the illustration will be formed. Now take a large sheet of stout white card or a drawing board with a piece of white paper pinned on it, and intersect the cone of light in the ways mentioned under (3), (4), (5), given above. In the first of these we shall have an ellipse, Fig. 176 marked out, in the second a parabola, Fig. 177, and in the last an hyperbola, Fig. 178.

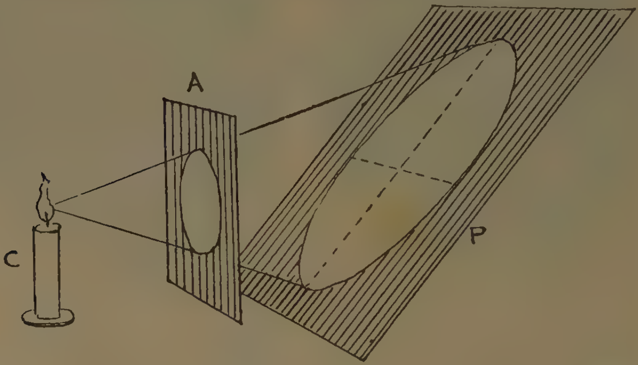

FIG. 176.—Showing the Formation of the Conic Section known as the Ellipse.

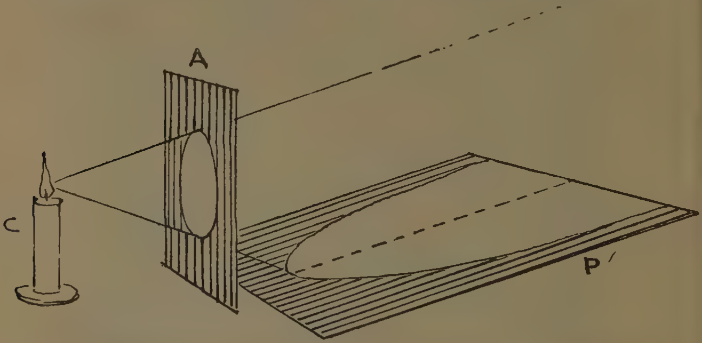

FIG. 177.—Showing the Formation of the Conic Section known as the Parabola.

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[1] Adapted from J. Humphrey Spanton.

The experiment reveals the fact that while the ellipse is a *closed* curve, the parabola and hyperbola are open, that is the two arms of the curve will never meet however far we may produce them. Hence, while comets which travel on elliptical orbits move round the sun like planets, those which journey on parabolic or hyperbolic curves only appear once and go away never to return again. The majority of comets move on orbits of the latter kind.

COMETS WHICH HAVE BEEN SEEN AT MORE THAN ONE VISITATION.

Name of Comet.	Period of Revolution.	Perihelion Distance (Earth's dist.=1.)	Aphelion Distance (Earth's dist.=1).	Eccentricity.	Inclination to the Ecliptic Plane.
Encke . . .	3·30 years	0·03	4·09	0·85	12° 54′ 58″
Tempel . . .	5·22 ,,	1·35	4·67	0·55	12 44 22
Brorsen . . .	5·46 ,,	0·59	5·61	0·81	29 23 48
Tempel-Swift	5·53 ,,	1·09	5·17	0·65	5 23 14
Winnecke	5·82 ,,	0·89	5·58	0·72	14 31 32
Tempel . . .	6·51 ,,	2·07	4·89	0·40	10 50 27
Biela	6·59 ,,	0·86	6·17	0·75	12 33 28
Finlay . . .	6·62 ,,	0·99	6·06	0·72	3 2 2
D'Arrest . .	6·69 ,,	1·32	5·78	0·63	15 42 41
Wolf . . .	6·82 ,,	1·59	5·60	0·56	25 14 33
Faye	7·57 ,,	1·74	5·97	0·55	11 19 40
Tuttle . . .	13·76 ,,	1·02	10·46	0·82	55 14 23
Pons-Brooks	71·48 ,,	0·77	33·67	0·95	74 3 20
Olbers . . .	72·63 ,,	1·19	33·61	0·93	44 33 53
Halley . . .	76·37 ,,	0·59	35·41	0·97	162 15 7

The above table shows that fifteen comets, having periods of revolution from 3·3 to 76·37 years, have been observed at more than one of their visitations. It will be seen that there is a great difference in each case between the distance from the sun of a comet at perihelion (shortest distance from the sun) and its distance at aphelion (greatest distance from the sun). Halley's comet, for instance, when at its perihelion point is only half the distance of the earth from the sun, but when it is at aphelion it is thirty-five times further than the earth from the sun. This is the direct outcome of the high eccentricity of the orbits of comets. How high this eccentricity is may perhaps be better understood when it is repeated that the eccentricity of the earth's orbit is only 0·016, and that of the orbit of Mercury,

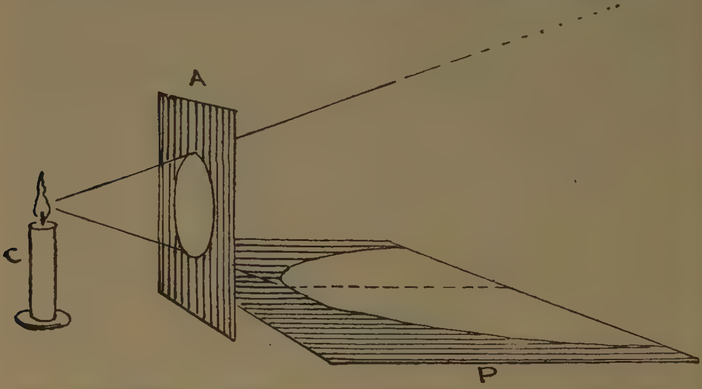

Fig. 178.—Showing the Formation of the Conic Section known as the Hyperbola.

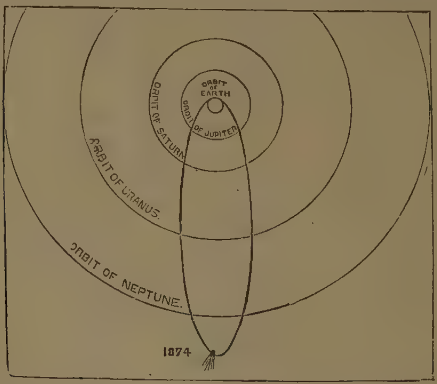

Fig. 179.—Orbit of Halley's Comet. Period of Revolution, seventy-six years.

the most eccentric of all the principal planets, is but 0·205, while that of Halley's comet, as the table shows, is as high as 0·97 (Fig. 179).

The inclinations of the orbits of comets are seen from the table to differ considerably. In the case of Biela's and Brorsen's comets, the orbits are not much inclined to the ecliptic—not so much, indeed as the orbit of Mercury ; but Faye's, Pons-Brooks's and Halley's comets move in greatly inclined orbits.

Some Cometary Biographies.—Halley's Comet.—The astronomer Halley in 1682 calculated the orbits of all comets which had been sufficiently observed to furnish the data for the calculations. He found that the elements of the comets which had appeared in 1531, 1607, and 1682 were practically identical. This led him to the conclusion that they represented one and the same body moving in an orbit with a period of 75 or 76 years. From this he deduced the fact that it should reappear in 1758, and he predicted that it would do so. As astronomers well know, it did appear in 1758, and again in 1835, and will next be seen in 1910.

Encke's Comet.—This one was the second comet proved to return periodically. From observations made during its appearance in 1818, Encke computed that it was moving in an elliptical orbit having a period of 3½ years. An examination of previous records of cometary observations showed that it had been seen on three separate occasions prior to the date given. Astronomers now see it regularly every 3½ years, and it is interesting in the fact that its period is diminishing slightly.

Biela's Comet.—This comet was discovered in 1772, and was afterwards found to move in an orbit with a period of about 6½ years. It was seen in 1832, but in 1839 it was not visible, being badly situated for observation. In 1845 it appeared, but it was split in two. The twin comet reappeared in 1852, but its constituents were at a greater distance apart than before ; and since that year neither of the parts has been seen, though according to the periodicity found for the comet, they should have appeared several times. In 1872, again, the comet was due to appear, but a great shower of meteors was seen instead, and showers occurred similarly at the end of November both in 1885 and 1892, when the earth was crossing that part of the comet's path where the comet ought to have been. It seems probable, therefore, that the showers of meteors represented the materials into which the original comet had broken up. The history of this comet thus supplies evidence in support of the view that comets are swarms of meteoritic rocks revolving round the sun.

Donati's Comet of 1858.—This, the most brilliant comet of modern times, was discovered in June 1858, but at first gave no signs of the magnificence which was observed later. It exhibited no tail until the August of the year in which it was first seen, when one developed with great rapidity. In October a great tail of a feather-like form (Fig. 180) had appeared, and what seemed to be two thin straight appendages were also visible. They probably represent one cone of extremely tenuous and luminous material. The greater thickness at the sides than straight through the axis of the cone gave the appearance of

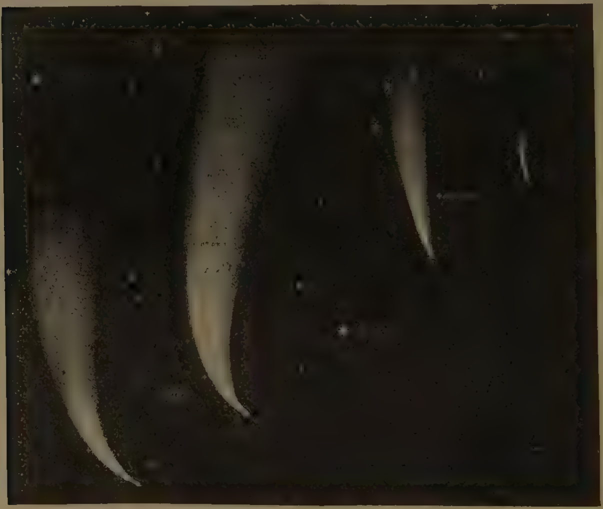

FIG. 180.—Donati's Comet of 1858, on different dates. The movement of the comet among the stars is shown, and also the growth of the tail.

two tails. The result of calculations of the comet's path indicate a period of about 2,000 years.

Meteorites and Shooting Stars

Their Nature.—*Shooting stars* are particles of matter which have become incandescent as a result of the heat developed by the friction between them and the earth's atmosphere through which they pass. This heat of friction is not always intense enough either to liquefy or convert the whole of a shooting star into vapour, and the still solid mass moves on through the atmosphere and reaches the earth's surface, when we know it as a *meteorite.*

Composition and Structure of Meteorites.—Meteorites are not all alike in composition and structure. At least three kinds have been recognised, which are as follows :—

1. *Aerolites*, which are similar in composition to certain ultra-basic rocks or peridotites. The minerals which are most commonly found are in consequence chiefly olivine (p. 192), and also enstatite (p. 192), bronzite (p. 192), augite (p. 191), anorthite (p. 189), and others.

2. *Siderites*, sometimes called *meteoric irons*, are composed almost wholly of metallic iron which generally contains about five per cent. of nickel, though sometimes more, alloyed with it.

3. *Siderolites* are intermediate in composition between the aerolites and siderites, being partly stony and partly metallic.

A microscopic examination of sections of the material ot meteorites, which was first effected by Mr. Sorby, has resulted in some interesting facts about these small bodies from space. Not only has undoubted evidence of an original molten condition been found, but certain minute rounded particles, often called *chondroids*, have been recognised ; and Mr. Sorby has suggested that they represent the product of the first solidification of an original vaporous substance, which was the first stage of a comet's existence—that they are in fact "ultimate cosmical particles."

Chemical Elements present in Meteorites.—In order of their abundance, the elements which have been found in any quantity in the substance of meteorites are—iron, nickel, phosphorus, sulphur, carbon, oxygen, silicon, calcium, aluminium. Many others have been recognised in smaller quantities, but no element other than those found in the earth has been as yet discovered in these bodies. But at the same time it must be pointed out that combinations of these elements which have been found in meteorites cannot be reproduced in the laboratory. One such compound is *schreibersite*, containing iron, nickel, and phosphorus.

Height of Meteors.—When the path of a meteor or shooting star with reference to fixed stars is noted by two or more observers in different places, the height of the meteor above the earth's surface can be calculated. The height of ordinary meteors has in this way been found to be seldom above 100 miles, but a few have been observed up to as much as 200 miles. The average values are given by Mr. W. F. Denning[1] as under:—

Height at first appearance . . .	73·6 miles.
„ „ disappearance	45·3 „
Length of path	62·1 „
Velocity	26·9 „ per sec.

The larger meteors, known as *fire-balls*, usually penetrate much lower into the atmosphere than the small ones do. As the student has learnt before, observations on the height of meteors afford a proof of the existence of atmosphere at these high altitudes.

Showers of Shooting Stars.—Whenever more than one shooting star is observed at a time, the paths which they all respectively pursue appear to radiate from one point, which is known as the *radiant point*. In reality, the particles which produce the shower move in nearly parallel lines, and the radiant point is simply the "vanishing point" of these lines—in other words, the whole effect is one of perspective.

Connection between Comets and Meteorites.—The late Professor Newton examined records of meteor showers, and found that bright showers had occurred on November 12th or 13th, at intervals of thirty-three years. From this observation he deduced the following conclusions:—"That the swarm of meteoroids which causes the November showers revolves round the sun in a definite orbit, which intersects the orbit of the earth at the point which the latter now passes on November 13th."

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[1] *Monthly Notices Roy. Astro. Soc.*, January 1897.

"The earth meets the swarm, on the average, once in 33·25

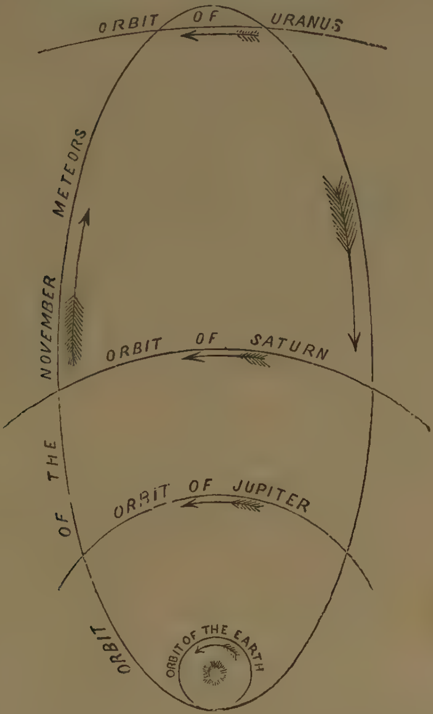

FIG. 181.—Orbit of the November Meteors, and of the Comet of 1861.

years. At other times the swarm has not arrived at the point of crossing, or has already passed it, and a meteoric shower cannot occur unless the earth and the swarm cross at the same time."

Professor Newton completed his investigations in 1864, and predicted that a shower should occur in the middle of November, 1866. The shower was actually observed. The form and dimensions of the orbit of the swarm were then calculated by other astronomers, and upon comparing these elements with those of the orbit of a comet observed by Tempel in 1861, the two sets were found to be practically identical (Fig. 181). The conclusion was, that "the November meteoric showers arise from the earth encountering a swarm of particles following Tempel's comet in its orbit." The next great meteor shower will occur in November, 1899.

The meteor showers seen in August every year shooting from the constellation Perseus, have been found in a similar way to be moving round the sun, in an orbit which is identical with that of another comet. The history of Biela's comet, previously referred to (p. 389), also adds more evidence of the intimate connection subsisting between comets and meteorites.

Nature of Comets.—As to the nature of comets, we cannot do better in this connection than quote the words of Sir Norman Lockyer,[1] who has made an exhaustive investigation of their composition. He remarks : "It is not too much to say that it is now generally agreed that a comet is a swarm of meteorites, each meteorite being on an average far from its neighbours. This result, indeed, might have been anticipated from considerations based upon the known large volume and slight masses of comets ; the latter are so small that they have never been known to appreciably disturb any of the planets, or even the satellites, by their gravitational attraction.

"In 1767 Jupiter and his satellites were entangled in a comet, yet the satellites pursued their courses as if the comet had no existence. The comet itself, however, was thrown entirely out of its course by the gravitational influence of the enormous mass of Jupiter, and its time of revolution changed from a long period to a short one of five and a half years.

"Biela's comet, first seen in 1826, appeared as a double comet in 1845. The extreme lightness of the two portions was shown by the fact that their mutual attraction was imperceptible, and that each performed its revolution independently of the other.

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[1] See *Meteoritic Hypothesis*, p. 239.

"The mass of individual comets probably never exceeds $\frac{1}{5000}$ of that of our globe. The meteorites comprising them must, therefore, be very far apart, seeing that this small mass is distributed through spaces millions of miles in extent.

"If this be conceded, it is fair to assume that a comet's luminosity is to a large extent produced by collisions of meteorites."

CHIEF POINTS OF CHAPTER XVII.

Jupiter is the largest planet. It differs from the terrestrial planets in physical character as well as in size. Rotates very rapidly; which fact, together with the probable plastic nature of the planet, causes the polar compression to be great. Rotation period varies slightly in different parts of the planet's surface. Belts parallel to equator always observed when the planet is visible. These may be belts of cloud, or they may be discolorations on the surface of a plastic mass. Five satellites, which may be used to determine the velocity of light.

Saturn is the ringed planet. It is lighter, bulk for bulk, than water. More flattened at the poles than any other planet. Resembles Jupiter in having cloud-belts, and a high velocity of rotation, which varies at different parts of the surface. The ring-system consists of an outer ring (*a*), separated from a middle ring (*b*) by a distinct interval, and a gauze or crape ring (*c*) inside the bright ring. Phases of the rings are caused by the plane of the ring-system being inclined 28° to the ecliptic. The rings consist, in all probability, of innumerable meteoritic particles. Satellites: eight, the largest number belonging to any planet.

Uranus, discovered in 1781. Markings very indistinct, therefore time of rotation and direction of axis doubtful. Four satellites, having orbits nearly perpendicular to plane of ecliptic, and revolving in a retrograde direction.

Neptune.—Irregularities were observed in the motions of Uranus, and from them the position of the disturbing planet (afterwards named Neptune) was deduced. Planet was found in its predicted place in 1846. No markings distinctly visible; therefore time of rotation and direction of axis unknown. One satellite, revolving in retrograde direction in orbit greatly inclined to ecliptic.

Comets.—Constituent parts: (*a*) the coma, (*b*) the nucleus, (*c*) the tail, (*d*) luminous jets and envelopes. Dimensions great, but mass as a whole small. No personal characteristic appearance, and can only be identified by the paths described. Movements, like those of planets, follow as a necessary consequence of the law of gravitation. Forms of orbits: (*a*) parabolic, (*b*) hyperbolic, (*c*) elliptic.

Periodic Comets.—Comet of 1682 shown to be similar to those of 1607 and 1531. Conclusion: that one comet was in question having a period of about 76 years. Prediction, by Halley, of the return of the comet in 1758. Verification of the prediction. Fifteen comets now known to appear periodically in a similar way, on account of their revolution in elliptic orbits.

Changes in a Comet while revolving round the sun. Comet first appears as faint patch of luminous haze. Bright nucleus develops; short tail appears; luminous jets shoot out from comet's head and bend back to form plume-like tail, which points away from the sun. Increase of activity until the nearest point to the sun has been passed, then a decrease.

Shooting Stars and Meteors are portions of matter rendered luminous by friction in passing through the earth's atmosphere. Sometimes the particles are not completely consumed, and the fragment falls to the earth as a meteorite. Showers of shooting stars occur periodically; hence conclusion that meteors move in orbits round the sun. Some swarms of meteorites shown to be revolving round the sun in the same orbits as certain comets. Conclusion: that certain comets are part of swarms of meteorites, the tails being gases driven off from the meteorites by heat developed by collisions.

QUESTIONS ON CHAPTER XVII.

(1) Describe the planet Saturn.

(2) How has the connection between comets and meteor-swarms been established?

(3) What is a comet, and what are the changes produced in it during its journey round the sun?

(4) Describe the changes which take place in the appearance of a comet during its journey round the sun.

(5) What is meant by a periodic comet? Describe the appearance of a comet as the sun is approached.

(6) Give an account of the observations which have been made on the physical features of Mars.

(7) Describe the surface markings of Mars, and state the causes to which they have been attributed.

(8) State what you know about the planet Jupiter.

(9) What do we know about the atmospheres of the Moon, Mars, and Jupiter?

(10) Write a short account of the discovery that some comets appear periodically.

(11) Describe the constituent parts of comets.

(12) State briefly the reasons for concluding that some swarms of meteorites move round the sun in the same orbits as comets.

(13) Trace the connection between meteors and comets.

(14) Describe the planet Mars. Can there be a transit of Mars across the sun's disc?

(15) State briefly the history of the discovery of the planet Neptune.

(16) Write a short account of Halley's comet.

(17) Give a brief description of the composition and structure of meteorites.

(18) What is meant by the radiant point of a shower of shooting stars, and how is the appearance produced?

(19) Name the chemical elements commonly present in meteorites.

(20) State what you know concerning the heights at which meteors appear and disappear. If the earth had no atmosphere how would the phenomena presented by shooting stars and meteors be affected?

CHAPTER XVIII

THE UNIVERSE

THE STARS : THEIR MAGNITUDES AND PROPER MOTIONS.

Constellations.—It will have been remarked by every observant person that the stars appear to be carried from the eastern to the western horizon as if they were all fixed to the inner surface of a solid celestial sphere, daily turning upon an axis passing through the north and south celestial poles. The student of Physiography at this stage knows that the apparent movement is produced by the rotation of the earth in an opposite direction to that in which the stars appear to move. The stars may for ordinary purposes be considered to be fixed—hence the term *fixed stars*—though it will be explained later that each has a real motion of its own in space. What we wish to draw attention to now is that the stars retain the same relative positions upon the celestial vault from night to night. This was long ago noticed by observers of the heavens, and it was seen also that some of the brighter stars form well-marked groups which constantly retain the same shape. These groups of stars, *constellations*, as they are called, have been given particular names, the names being mostly those of characters in heathen mythology. Nearly eighteen hundred years ago the great Ptolemy gave a list of forty-eight constellations adopted in his time ; and astronomers of the present day follow the grouping he described, adding about twenty other groups to supplement the earlier ones.

This division of stars into constellations is convenient because it enables the different parts of the heavens to be given distinguishing names, just as different parts of the world bear the names of different countries. If an astronomer sees a shooting star fall across any particular constellation, he is familiar enough with the sky to say whether it crossed the constellation Perseus, or Andromeda, or Leo (the Lion) or any other group. He knows roughly the boundary line of each group quite as well as a boy should know the boundary lines of different countries upon the earth, and so he is able to name the constellation in which any celestial phenomenon observed by him on a fine night occurred.

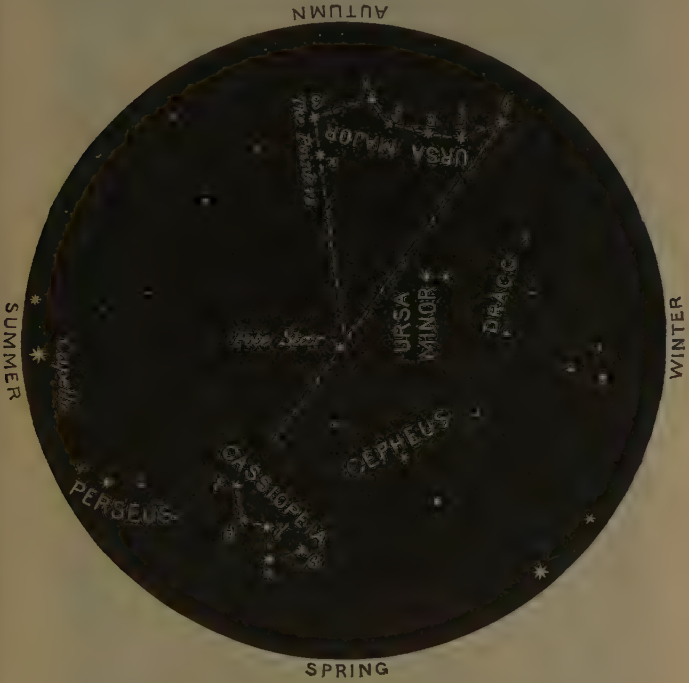

FIG. 182.—View of the Sky Looking North. To find the aspect of the circumpolar constellations at about 10 p.m. during any season of the year, turn the page until the name of the season is at the bottom.

The chief constellations seen when looking towards the northern sky on a starry night are shown in Fig. 182. These groups are always visible at night in England when the sky is clear, and the different stars retain the same relative positions though the group which is above the Pole Star at one season of the year is below it at the same time of night six months later. But whatever the position in which the constellation of the Great Bear (Ursa Major) is seen, Cassiopeia always appears on the other side of the Pole Star

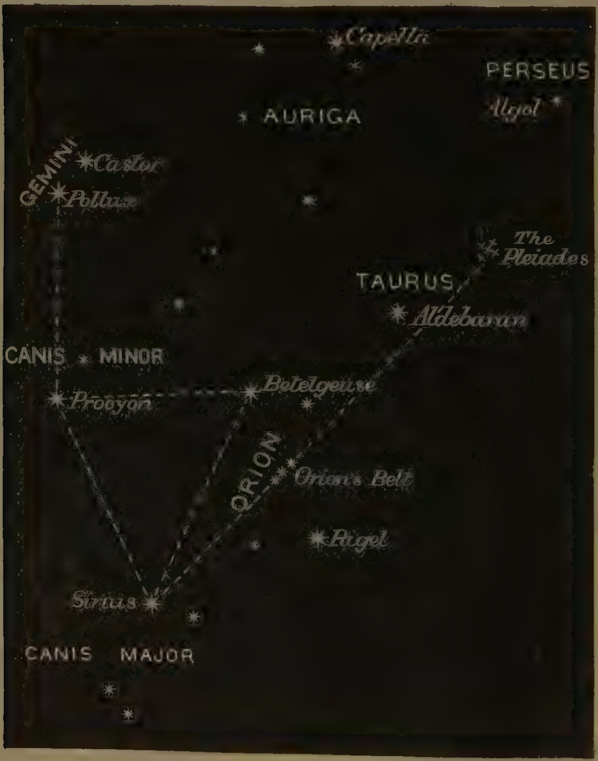

FIG. 183.—Some Stars Visible when looking South about 10 p.m., about January. The names of stars are in small letters, and of constellations in large letters.

Three bright stars in a line are seen when looking towards the south in the winter months about nine o'clock; these belong to the constellation of Orion, shown with parts of other constellations in Fig. 183. Unlike the northern constellations illustrated by Fig. 182 the groups around Orion are only visible in certain months of the year; during other months they are near the sun, and so are hidden by the sun's beams.

Nomenclature of Stars.—It has been said that constellations are analogous to countries; the analogy can be carried further, stars being like towns upon the earth's surface. To distinguish the stars of one constellation from another, letters of the Greek alphabet are used, the brightest star in a constellation being Alpha (*α*) the next brightest Beta (*β*), and so on. Thus, *α*-Lyræ is the brightest star in the Lyre, and *β*- Ursae Majoris is the second brightest star in the Great Bear. The Roman alphabet is used when the Greek letters are exhausted.

Most of the bright stars also have special names; for instance, the following are the names of the brightest stars visible in England:—

α Canis Majoris, or Sirius
α Bootes, or Arcturus
β Orionis, or Rigel
α Aurigæ, or Capella
α Lyræ, or Vega
α Canis Minoris, or Procyon
α Orionis, or Betelgeuse
α Eridanus, or Acharnar
α Tauri, or Aldebaran
α Scorpii, or Antares
α Aquilæ, or Altair
α Virginis, or Spica
α Piscis Australis, or Fomalhaut
β Geminorum, or Pollux
α Leonis, or Regulus
α Geminorum, or Castor

Only the brighter stars in a constellation are favoured with proper names, or even designated with a letter of the Greek alphabet; the fainter ones are known by their numbers in particular catalogues. Thus "Lalande 26,134," abbreviated to "Ll. 26,134," means the star's number is 26,134—in a catalogue made by the astronomer Lalande. Such star catalogues contain lists of stars arranged according to their right ascensions and declinations. They are, therefore, analogous to the lists given in atlases of longitudes and latitudes of places on the earth.

Star Magnitudes.—Every one has observed that the stars are of different brightnesses. There are a few which force themselves upon the attention on account of their sparkling brilliancy ; while others are so faint that, to see them at all, the sky must be free from haze, and the observer must have keen eyesight. There are, in fact—and every one must have noticed it—various degrees of stellar glory, ranging from the brightest stars to those on the borders of invisibility. It is necessary in astronomy to adopt a scale of brilliancy, so that the brightness of a star can be expressed by reference to it. The system followed works upon the basis that on the average the light received from one of the brightest stars in the heavens is 100 times greater than that from a star which is only just visible to the naked eye. The difference of brightness between these two extremes could be divided into any number of steps, but for convenience the stars visible to the unaided eye are taken to be included in six degrees or orders of brilliancy ; the brightest stars being classified as stars of the first magnitude, and the faintest naked-eye stars as stars of the sixth magnitude. Taking the average sixth-magnitude star as the unit, the average fifth magnitude star is 2·51 times brighter than it ; the fourth magnitude is 2·51 times brighter than the fifth ; the third magnitude 2·51 times brighter than the fourth ; the first magnitude 2·51 times brighter than the second. A star of any one magnitude is thus 2·51 times brighter than a star of the next fainter magnitude, and 2·51 less bright than a star of the next higher magnitude. By adopting this light ratio of 2·51, which is the fifth root of 100, the brilliancy of a star of the first magnitude works out 100 times greater than that of a star of the sixth magnitude.

The relation between the magnitudes may be put in tabular form thus : A star of the first magnitude

is equal in	brightness to .	2·5	stars of the	second	magnitude
"	"	6	"	third	"
"	"	16	"	fourth	"
"	"	40	"	fifth	"
"	"	100	"	sixth	"

This system of classifying stars into magnitudes is not only applied to stars which are seen with the naked eye, but also to those which are revealed by the telescope. If a star occupies an intermediate position between two magnitudes, say between the third and fourth magnitudes, its magnitude may be expressed by a fraction, thus—3·6, or $3\frac{1}{2}$.

Number of Stars.—A glance at the sky on a fine night gives the idea that the stars are countless; but this is not so actually. If the whole of the heavens could be seen at any instant, less than 6,000 stars would be visible to the naked eye, and as only one-half the celestial sphere can be viewed at one time, only about 3,000 stars could be counted. An observer situated at the North Pole of the earth would see all the stars contained in the northern celestial hemisphere, and an observer at the South Pole would see all those in the southern celestial hemisphere. It has been found that 3,391 stars are clearly visible in the part of the celestial sphere between the North Pole of the heavens, and the parallel of 35 degrees south of the celestial equator. The numbers in each magnitude are as follows:—

First	magnitude	about	14	stars
Second	,,	,,	48	,,
Third	,,	,,	152	,,
Fourth	,,	,,	313	,,
Fifth	,,	,,	854	,,
Sixth	,,	,,	2,010	,,
Total	. . .		3,391	stars

It will be noticed that the stars become more numerous as the magnitude becomes fainter.

How Telescopes assist the Sight.—Stars fainter than the sixth magnitude can only be seen with optical aid. Even a small telescope is sufficient to add very considerably to the visible universe. With a telescope less than 3 inches in diameter it is possible to see about 300,000 stars in the northern celestial hemisphere, and with the largest telescopes now in use something like 100,000,000 stars are brought within the ken of the observer. Telescopes enable us to see faint stars for a very simple reason, namely, by grasping a greater number of faint rays than can enter the eye without their aid. The pupil of the human eye—the portal through which rays of light enter to affect the retina and produce the sensation of sight—is about one-fifth of an inch in diameter. As the areas of circles are proportional to the squares of the diameter, the area of the average eye-pupil would be 25 times greater than it is now if the diameter were an inch instead of one-fifth of an inch, and the result would be that the bundle of rays grasped by the eye would be 25 times greater. A telescope enables us as it were to artificially enlarge the eye-pupil. The object glass is the enlarged eye which is turned towards the heavens, and it catches a bundle of rays as much larger than the bundle which enters the unaided eye as the aperture of the telescope is greater than

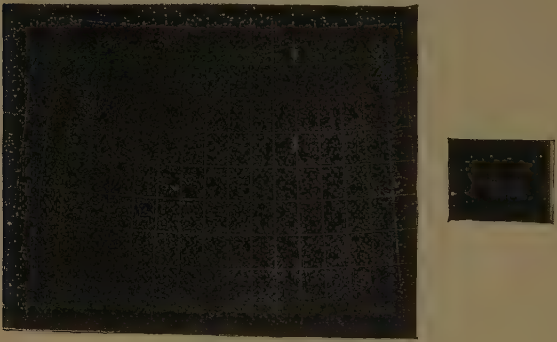

FIG. 184.—The small right-hand picture shows a small piece of the Sky as seen with the naked eye. The left-hand picture shows the same piece seen through a three-inch telescope. From Flammarion's *Astronomie Populaire*.

the area of the human eye-pupil. The rays thus grasped are brought to a focus by the object glass; and though the few faint rays which can enter the naked eye may be insufficient to produce the sensation of sight, a larger number of the rays when concentrated to a point by a telescope, show stars to exist in places where the eye alone can see nothing. Large telescopes are thus required expressly to obtain "more light," and it is on account of their ability to do this that they are able to reveal stars beyond the grasp of the unaided eye (Fig. 184).

The magnifying power of a telescope is another matter; it depends upon the relation between the focal length of the object glass and that of the eye-piece. Several eye-pieces magnifying by different amounts are usually supplied with a telescope; but

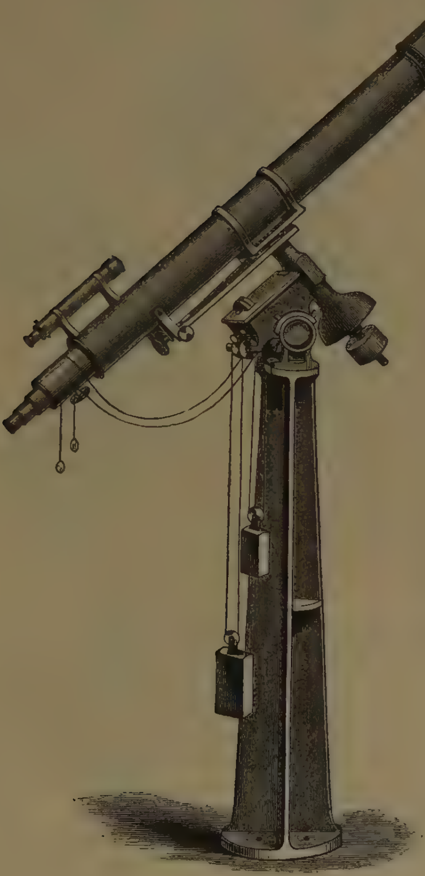

FIG. 185.—Sir Howard Grubb's Equatorial Telescope mounted upon metal pillar. The weights are in connection with clockwork used to make the telescope follow the apparent motions of the stars.

there is a limit to the powers which can be usefully employed, on account of the wavering condition of the earth's atmosphere. A magnification of about 250 diameters is sufficient for most observations, and it is not often possible to exceed a power magnifying more than 1,000 diameters on even the largest telescopes.

Photography as an Aid to Astronomy.—During the last 40 years the power of a telescope to reveal faint objects has been considerably extended by substituting the sensitised plate of the photographer for the eye of the astronomer. As many as 16,000 stars have been photographed in an area of sky in which a telescope 3 inches in diameter would only show about 200 to the most keen-sighted observer, while the naked eye is unable to distinguish more than a dozen stars in the same sky surface. There are two chief reasons why the photographic plate should be able to see so much farther into the infinitude of space than the human eye. In the first place, it is sensitive not only to light-rays which affect the eye, but also to a long range of ultra-violet radiations which are incapable of producing any visual effect; and, moreover, it can accumulate the impressions it receives, which is more than the retina of the eye can do. The light of an object may be so faint as to be beyond the visual grasp of any observer using any telescope, but the photographic plate will show it. And on account of the cumulative action which the plate is able to exercise, the longer the photographic eye is turned heavenwards, the more is it able to see and register upon its surface.

Photographic Star Charts and Catalogues.—A scheme for mapping the heavens by photography was drawn up at a congress of astronomers which met in Paris in 1887. It was decided that refracting telescopes of the type shown in Fig. 186 should be employed in the work. By adopting a definite proportion of aperture to focal length a minute of arc upon the heavens is represented by 1 millimetre upon the photographic plate. These dimensions will perhaps be better understood by pointing out that a minute of arc is about $\frac{1}{32}$ of the sun's diameter, and a millimetre is $\frac{1}{25}$ of an inch; so the size of the sun's image shown by one of the telescopes in use for photographing the heavens is about $1\frac{1}{4}$ inches. Upon this scale the entire map of the sky will, when completed, cover a globe about 22 feet in diameter.

Two sets of photographs are being taken of every part of the heavens—one with an exposure sufficient for stars down to the eleventh magnitude to leave their impressions, and another series with longer exposures showing stars down to the fourteenth magnitude. The position of the stars upon the first series of plates are being accurately measured and tabulated to form a catalogue which will eventually contain about 1,500,000

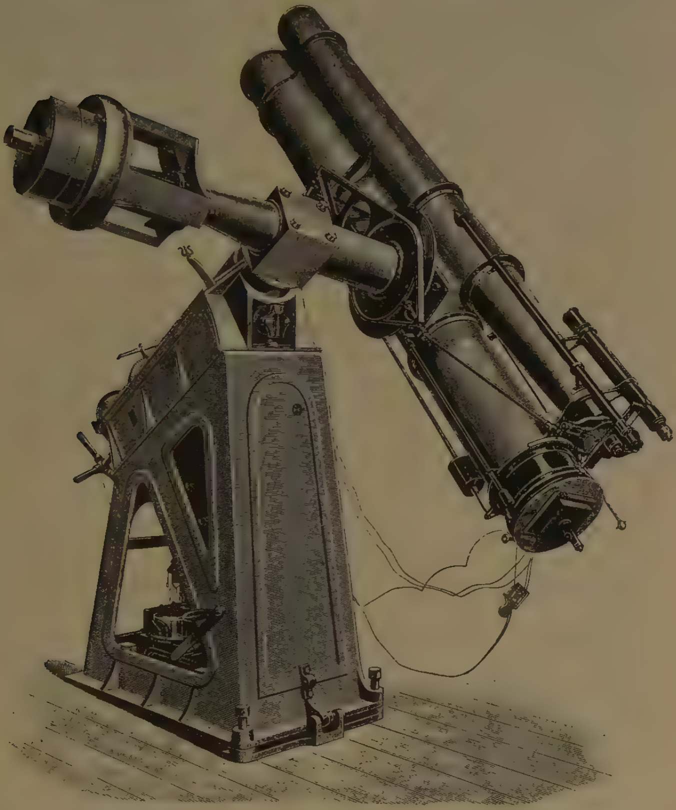

FIG. 186.—The Standard Form of Equatorial Telescope constructed by Sir Howard Grubb for the International Photographic Survey of the Heavens. The small telescope is for finding objects in the sky, the upper large one is a guiding telescope, the lower large one is the photographic telescope.

stars; the second series of plates will contain many more stars (about 20,000,000 altogether), and will be used for constructing the photographic star map.

It will be understood from what has already been stated (p. 400) that it would be impossible to photograph the whole of the heavens from one place. To carry out the scheme, co-operation is necessary, and a number of astronomical observatories, situated in different parts of the world, are participating in the work. Each observatory is assigned a certain region of the sky to portray, and piece by piece the photographic record of the sky is being built up. About ten thousand separate plates are required to portray the whole celestial sphere, and ten thousand more to register the positions of stars, for the photographic star catalogue. When the whole sky surface has been covered, astronomy will possess a document which will not only be of value at the present time, but will also be a priceless work of reference for future epochs.

Proper Motion of Stars.—It has already been pointed out that if the right ascension and declination of a star at the present time be compared with observations made say a hundred years ago, a difference would be noted. The alteration is chiefly due to precession; but even when allowance is made for this and also for the annual parallax, refraction, nutation and aberration, instrumental defects, and other causes which vitiate the observations by changing the *apparent* positions of stars, there would still be a difference between the two determinations after the lapse of a few years, and this difference is due to the star's own or proper motion through space.

The proper motion of a star can evidently not be made by direct observation or measurement at one time, but only by noting the difference between accurate observations made at two different epochs, after all corrections have been applied. The transit instrument is brought into requisition in this determination because it is the instrument which is utilised to accurately determine the position of stars. The right ascensions (analogous to terrestrial longitudes) and declinations (analogous to terrestrial latitudes) of stars are constantly being determined by means of the transit instrument. After all allowances have been made, the right ascensions and declinations are found to differ at different epochs. In general, the difference is only a fraction of a second of arc, but in a few cases it is much more. The annual proper motion is found by taking the mean place in right ascensions (m and m') of a star at two different epochs and dividing the difference between the observations by the number of years (t) in the interval, after subtracting the effects of precession (P), &c.; or, as expressed by the formula—

$$\text{Annual proper motion} = \frac{m - m'}{t} - \text{P}.$$

The proper motion of a few stars in right ascension and declination are shown below.

Star.	Proper Motion in Right Ascension.	Proper motion in Declination.
61 Cygni	$+5''.38$	$+3''.30$
Procyon	-0.71	-0.98
Arcturus	-1.17	-1.96
Sirius	-0.51	-1.14
η-Cassiopeiæ	$+1.78$	-0.72

Of course the proper motion of a particular star is really in one definite direction, and what is measured are the component velocities from which the uniform angular rate of motion of the star among its fellows is deduced.

We give above the motions of certain stars in right ascension and declinations merely to show how the positions are affected annually. The + sign in the column of declination denotes a motion towards the north, and a − sign signifies motion towards the south.

The following table gives the names of six stars with the largest observed proper motions.

Star.	Magnitude.	Proper Motion per annum.
Groombridge, 1,830	6	$7''.05$
Lacaille, 9,352	7	6.97
Cordoba, 32,416	8.9	6.08
61 Cygni	6	5.14
Lalande, 21,185	7.8	4.75
ϵ-Indi	5	4.60

It will be seen from this that the greatest proper motion of a star *across* the celestial vault is seven seconds of arc per annum. At the distance of this flying star (1830, Groombridge) this angular motion means a velocity of more than two hundred miles per second across our line of sight. The direction and amount of the annual proper motion of the stars in the Plough, or Great Bear, constellation are shown in Fig. 187

By means of the spectroscope the proper motions of stars towards, and away from, the earth have been determined. It has been found that the star Gamma (γ) Leonis is approaching the Solar System with a velocity of about twenty-four miles per second, and that Alpha (α) Tauri (Aldebaran) is receding from our system with a velocity of thirty miles per second.

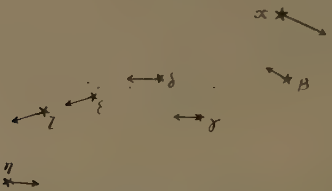

FIG. 187.—Direction and Relative Amount of the Annual Proper Motions of the Stars in the Plough.

Proper Motion of the Sun.—When the proper motions of a large number of stars are considered, it is found that there is a general movement away from one point in the sky, and towards another point on the opposite side of the celestial sphere. This drift is explained by the proper motion of the sun. The sun is moving through space, and carrying the earth and other members of the Solar System with it. At the point of the sky towards which we are moving—the *apex of the sun's way*, as it is called—the stars have a tendency to spread out; while on the opposite side of the heavens, near the point—the anti-apex—from which we are moving, the stars show a general tendency to close up. The point towards which the Solar System is moving is near the star Alpha Lyræ (Vega), and the velocity is six or eight miles per second. The spreading out and the closing up is similar to the appearance seen in front and behind when walking down an avenue of trees.

Variable Stars.—A large number of stars vary in brightness from time to time the rise and fall of brilliancy being often performed in a definite period of time. These are variable stars, and they may be divided into several classes according to the nature of the fluctuations of their light. A convenient classification made by Professor E. C. Pickering[1] is usually adopted; it is as follows:—

I. Temporary stars, which appear suddenly, and gradually fade away during the next few months. Examples, the new star observed by Tycho Brahe in 1572, new star in *Corona Borealis* in 1866, and the new star in *Auriga* in 1892.

II. Stars undergoing great variations in light, and passing from a maximum to a minimum and then to maximum again in periods from six months to two years. Examples, *Omicron* (*o*) *Ceti* and *χ-Cygni*.

III. Stars undergoing slight changes of brightness according to laws as yet unknown. Examples, *α-Orionis* and *α-Cassiopeiæ*.

IV. Stars whose light is continually varying, but the changes are repeated with great regularity in a period not exceeding a few days. Examples, *β-Lyræ* and *δ-Cephei*.

V. Stars which during the greater part of their time remain unchanged in brightness, but at regular intervals lose in the course of a few hours a large part of their light, and regain it with equal rapidity. These changes appear to be repeated with the greatest regularity, so that the interval can be computed in some cases within a fraction of a second. Examples *β-Persei* (also called Algol), and *S. Caneri*.

New or Temporary Stars.—Only a few new or temporary stars have been observed. In 1572, a bright star which surpassed Sirius in brilliancy appeared in the constellation Cassiopeiæ; and the famous astronomer, Tycho Brahe, made minute observations of the changes it underwent during the fifteen months it was visible. As the star faded away its colour changed from white to yellow, and then to red.

In our own time we have the star which suddenly increased in brightness in *Corona Borealis* in 1866. From a star of the eighth magnitude it rapidly grew to the second magnitude, and in a few months sunk again to its original insignificance. In 1892 a strange star appeared in the constellation *Auriga*; and though it did not get bright enough to be a conspicuous object, it was very closely studied by astronomers, both to determine the rate of diminution of its brightness, and also to analyse its light.

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[1] *Proceedings of the American Academy of Arts and Sciences*, vol. xvi., 1880.

It has been suggested that new stars are produced by enormous eruptions of luminous matter from within a comparatively dark crust, and though this theory may roughly account for the phenomena it is not altogether satisfactory. Sir Norman Lockyer's view is that "new stars, whether seen in connection with nebulæ or not, are produced by the clash of meteor swarms," and many facts can be adduced in support of it.

Typical Variable Stars.—The star Omicron (*o*) Ceti, also called *Mira*—the wonderful,—is a typical example of the large class (Class II) of stars which periodically and slowly rise and fall in brightness. When at its maximum brightness, Mira is a star of the second or third magnitude. A couple of months after its maximum, the star has sunk to the eighth or ninth magnitude, and remains in this diminished state for nearly eight months, when it runs up again to the second or third magnitude. The whole period of change from one maximum to the next is about eleven months, or 332 days.

The star Beta (β) Lyræ is a good example of the class of stars which are continually varying in light, going through a series of changes in the course of a few days, which variations appear to be repeated exactly. A peculiarity of the class is that in a complete period of alteration there are two, and sometimes three, maxima of different magnitudes and two or three minima of different degrees of faintness. The variation in the light of Beta Lyræ from one minimum to the next of the same degree may be set down as follows:—

	Mag. 4·9, minimum.
Star brightens for 3d. 2h. to	Mag. 3·5, maximum I.
,, dims for . 3d. 7h. to	Mag. 3·9, secondary minimum
,, brightens for 3d. 3h. to	Mag. 3·5, maximum II.
,, dims for . 3d. 10h. to	Mag. 4·9, minimum.
Period 12d. 22h.	

In the case of this star two causes of variation seem to be superimposed, one producing one maximum and one minimum in each period, the other two maxima and two minima.

The most interesting class of variable stars is Class V, of which Algol is a good example. The course of changes of this star in its period are as follows :—

Algol is for 2d. 12h. 0m. a star of . . . 2nd mag.
It sinks in 0d. 4h. 30m. from 2nd mag. to 4th mag.
It remains 0d. 0h. 18m. at the . . . . 4th mag.
And rises in 0d. 4h. 0m. from 4th to . . 2nd mag.
Period 2d. 20h. 48m.

Causes of Stellar Variability.—Several explanations have been put forward to account for the light changes of variable stars. In the case of stars which show irregular light variations as in Class III, the suggestion is that the variability of lustre might be produced by the existence of dark spots on the stars similar to those which appear upon the sun, and which are more or less abundant at different times, just as are the solar spots. Again, if the non-luminous matter covers a large part of a star's surface, and the star is supposed to be in rotation, a regular and periodic change of light will be seen as the luminous and non-luminous parts are turned towards us. This theory was once held to account for the phenomenon presented by stars of the Algol type, which remain bright for most of the time but suddenly fade in brightness, and after a few hours as suddenly gain their original brilliancy.

The theory will not, however, explain the variations of Algol and of other stars of the fifth class. It has been definitely proved that these stars owe their variability to the periodical eclipse of their light by a dark companion.

The revolution of one mass round another has been put forward by Sir Norman Lockyer as a general explanation of all light changes shown by celestial bodies. His conclusions[1] are here reproduced.

Regular Variability.—"All regular variability in the light of cosmical bodies is caused by the revolution of one swarm or body round another (or their common centre of gravity).

"In the case of the revolution of one swarm round another an elliptic orbit is assumed, and the increase of light *at maximum* is produced by collisions among the meteorites at periastron.

"In the case of the revolution of a swarm round a condensed

Meteoritic Hypothesis. J. Norman Lockyer, p. 475.

body, the increase of light *at maximum* is produced by the tidal action set up in the secondary swarm.

"In the case of one condensed body revolving round another the reduction of light *at minimum* is caused by an eclipse of one body by the other. This can only happen when the planes of revolution of the secondary body passes very nearly through the earth."

Irregular Variability.—"All irregular variability in the light of cosmical bodies is caused (*a*) by the revolution of more than one swarm or body round another (or their common centre of gravity); or (*b*) by the interpenetration of meteoritic sheets or streams."

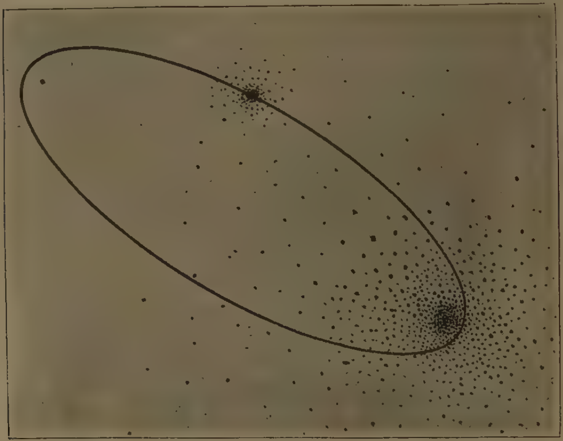

FIG. 188.—Revolution of a small swarm of Meteorites around a larger one. Suggested by Lockyer to explain variability of stars.

Fig. 188 illustrates Sir Norman Lockyer's explanation of the variability of stars like Mira Ceti. A small swarm of meteors is shown revolving in an orbit round a larger one. The larger one is really the Star Mira, but we cannot of course see the individual meteorites whose collisions produce the luminosity. When the small swarm approaches the larger one the number of collisions is increased, and so the brightness of the star is increased. As the disturbing swarm passes away, the star gradually cools down to its normal condition, and remains at its customary magnitude until the small swarm of meteors approaches it again.

CHIEF POINTS OF CHAPTER XVIII.

Constellations are groups into which astronomers have arranged the stars according to positions on the sky. Ptolemy (140 A.D.) named forty-eight groups, and about twenty names since added are accepted. Constellations are analogous to countries, names of bright stars are analogous to names of cities ; and a star catalogue is analogous to the index at the end of an atlas.

Stars are arranged in Magnitudes according to their brilliancy, the first magnitude including the brightest stars and the sixth the stars just visible to the naked eye. It is agreed that a star of any magnitude is two-and-a-half times brighter than one a magnitude fainter. The magnitude, or apparent brightness of a star depends upon (*a*) distance from the solar system (*b*) extent of luminous surface (*c*) quality of light emitted.

Number of Stars.—On the best night about 2,500 can be seen with the naked eye at one time. A three-inch telescope will show 300,000 in the same celestial hemisphere, and the largest telescope about 100,000,000 in the whole sky. There seems no limit to the number of stars that can be photographed.

Photography reveals Stars and other celestial objects because (*a*) the photographic plate can store up faint impressions whereas the eye cannot do so (*b*) it is sensitive to a longer range of vibrations than is the human retina. A photographic map of the sky is in course of construction, and photographs are being taken to furnish permanent records of the places of stars upon the sky.

The Proper Motions of Stars are *real* motions through space, as distinct from the *apparent* movements due to the earth's rotation (producing diurnal motions), revolutions (producing aberration and parallax), and shifting of the earth's axis (producing precession, nutation, &c.). The change of position determined after all these apparent movements have been eliminated is the star's proper motion.

The Sun is Moving through Space, and carrying all the members of the Solar system with it. The consequence is that near the point of space towards which the sun is moving (*the apex of the sun's way*) the stars show a tendency to open out, whilst near the point behind us (the *anti-apex*) they show a tendency to close up.

Variable Stars may be thus classified. (*a*) New or temporary stars which appear suddenly and then gradually fade away (*b*) stars which rise and fall in brilliancy in a period from six months to two years long (*c*) stars which are subject to irregular variations of light. (*d*) Stars which continually vary in light in a period of a few days. (*e*) Stars which are bright most of the time, but their light is periodically eclipsed.

Suggested Causes of Variabiltiy are (*a*) luminous material bursting through a less luminous crust (*b*) increase and decrease of spotted surface, similar to the periodic increase and decrease of spots upon the sun (*c*) the collisions produced by one swarm of meteorites revolving round another, the greatest number of collisions being produced when the two swarms are nearest one another. (*d*) The revolution of a dark star round a bright one.

QUESTIONS ON CHAPTER XVIII.

(1) What is meant by the proper motion of a star, and by a star's motion in the line of sight?

(2) Describe briefly how the proper motions of the stars have been determined from observations made with the transit instrument.

(3) Give an account of the various classes of variable stars and the suggested causes of variability in each case.

(4) How has the variability of stars been accounted for?

(5) How have the phenomena of new and variable stars been explained?

(6) What explanations have been given or the variability of stars?

(7) What is a constellation? Give a sketch showing the relative positions of a conspicuous group of stars visible when looking north on a fine night in winter.

(8) Describe the system adopted in designating stars. Give the names of six bright stars.

(9) What exactly is meant by the "magnitude" of a star? How many stars of the sixth magnitude would be required to equal in brightness a single star of the first magnitude?

(10) Why is it that more stars can be seen through a telescope than by the unaided eye?

(11) More stars can be photographed with a telescope than can be seen with the same telescope. How do you account for this?

(12) Write a short account of the photographic star chart and catalogue now in course of construction.

(13) What facts are usually tabulated in a star catalogue?

(14) How far is it correct to speak of the "fixed stars"? Mention the chief changes to which the position of a star is subject, and state in two or three lines the cause of each of them.

(15) Describe briefly the reasons for concluding that the sun has a proper motion through space.

CHAPTER XIX

THE UNIVERSE

DOUBLE STARS, CLUSTERS, AND NEBULÆ

Double Stars.—A number of stars in the heavens appear as single points of light when seen with the naked eye, but when a telescope is used they are found to be really two or more stars very close together. The star Castor is an example of this. To the unaided eye it appears as a single bright star, but a small telescope shows it to be made up of two, one of the pair being a magnitude brighter than the other. Another star, Epsilon (ϵ) Lyræ, is a still more striking example. A small telescope will divide the star into two components, and a telescope of moderate dimensions will show that each of these two members also consists of two, thus making what appears to be one star when seen with the eye alone into four when observed with optical aid. This quadruple system is known as the "double double star."

The components of a double star are sometimes nearly equal in brightness but more often they differ in brightness, in which case they also differ in colour. The star Gamma (γ) Andromedæ, for instance, consists of two stars, one of the third magnitude is of a golden yellow white colour, the other of the fifth magnitude being blue. Beta (β) Cygni—a star easily separated into its two components—consists of a yellow star of magnitude three and a blue star of magnitude seven.

Optical and Physical Doubles.—Stars may appear double merely because they are seen in the same direction, though one may be immensely further from us than the other Such stars are termed *optical* doubles, to distinguish them from the *physical* doubles composed of two or more luminous bodies revolving round one another. Accurate measurements of the position of two stars close to one another show in the course of a few years whether the stars actually form a *binary* system or not. If the stars are found to move independently of one another in a straight line, their duplicity is only apparent; but if the component stars are found to be moving in concave curves relatively to each other, then it is concluded that they are really a pair of revolving suns—a binary star (Fig. 189).

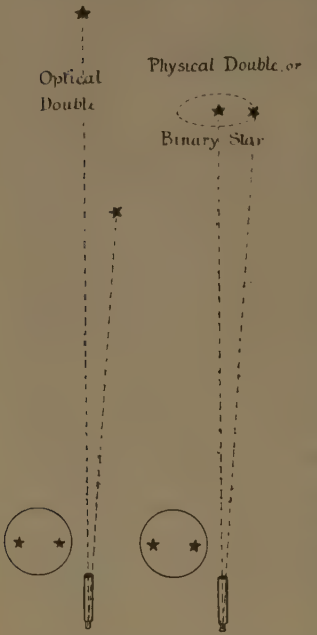

FIG. 189.—To show that though a Star may look double it is not necessarily a true Binary.

To determine the orbit of a double star it is necessary to measure the relative positions and distances apart of the components over a long series of years. The measurements are made by means of a micrometer, a telescopic accessory for measuring small angles in the field of view. The contrivance may conveniently be described here.

The Parallel Wire Micrometer.—Two fine wires or spider threads are arranged parallel to one another and in the same plane, upon sliding brass pieces held in a frame. Connected with each brass piece is a finely cut screw, having a head an inch or so in diameter graduated around its circumference. A pointer is fixed near each of these graduated circles to indicate how much the screw is turned. By turning either of the screw-heads the parallel wires of the micrometer can be made to approach one another or to move further apart. Two fixed wires are arranged close together at right angles to the movable ones. The instrument thus constructed is placed at the eye end of the telescope, and the usual eye-piece is used in connection with it (Fig. 190). When so arranged, the observer sees the wires projected upon the field of view he happens to be observing.

The Wire Micrometer used upon Double Stars.—To measure the angular distance between two stars, the micrometer is turned until the stars lie between the two fixed wires, so that the line of direction between them is parallel to the wires. The two movable wires are next turned by means of the screw-heads until one lies upon each star (Fig. 191). The amount of separation can then be determined by means of the graduated screw-heads, which indicate zero when they are close together and from that to 100 as they are separated. It will be evident, however, that what is obtained by the observations is not the angular distance between the stars, but the distance in terms of revolution of the screw-head. To find the angle represented by a turn of the micrometer screw so as to be able to convert the reading of the graduated screw-heads into angular measure, the wires are separated by, say, 20 revolutions of the screw, and the

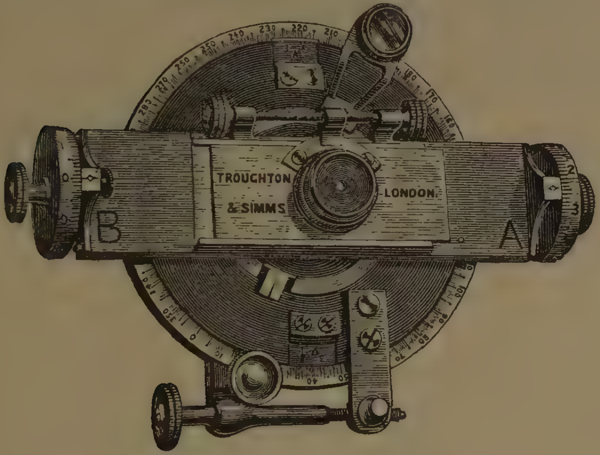

FIG. 190.—BA, Parallel Wire Micrometer, with position circle.

time which a star near the celestial equator takes to pass straight across from one to the other is observed. In one second of time such a star appears to pass over 15 seconds of arc, so that if the star took 30 seconds of time to pass from one wire to the other, the equivalent angle is $30 \times 15'' = 450$ seconds of arc, and dividing this by 20 will give the value of one revolution of the screw in angular measure. When this value has once been determined, the readings of the micrometer screw can readily be converted into their equivalent angles.

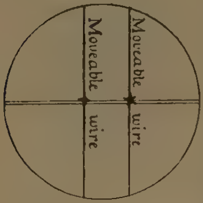

FIG. 191.—The Wires in a Parallel Wire Micrometer.

The micrometer is not only used to determine the angular distance between the components of a binary star; it is employed also in many other determinations, such as the measurements of the diameter of the planets, the dimensions of a sun spot, or the size of a lunar crater. The instrument is, indeed, absolutely indispensable to a properly equipped observatory.

The Position Circle for defining Celestial Directions.—In observations of double stars, and in other cases also, it is necessary to define the direction in which objects lie upon the heavens. For this purpose an arrangement known as a *position circle* usually forms part of the micrometer. It consists of a graduated circle and an indicator to show the angle through which the whole micrometer is twisted in one direction or the other. The position circle is a kind of celestial compass card, the chief difference between it and an ordinary compass card being that directions are expressed in angles instead of cardinal points. To use the instrument, it must first be set so that the vertical cross wire shown in Fig. 192 lies upon a celestial meridian. This is done by turning the circle until a star is carried in its diurnal motion straight across the other cross wire; and as the diurnal motion of every star is at right angles to the meridian, the line at right angles to that along which the star travels evidently lies upon a meridian, that is, due north and south. All that need now be done to find the position angle of the imaginary line connecting two stars or other objects is to twist the position circle round until it lies parallel to the direction under observation and read off the angle through which it has been turned in order to accomplish this. The angles are read from the north point, from 0° to 360°, through the east, south, and west points, as shown in Fig. 192.

Orbits of Double Stars.—Astronomers have found about twelve thousand double stars, and between two and three hundred have been proved to be in revolution round one another in periods from about six to more than fifteen hundred years. Only a few of these have been observed throughout a revolution, but sufficient measures have been made of the changes of position angle and angular separation of nearly fifty binary stars to enable the orbits and periods to be determined.

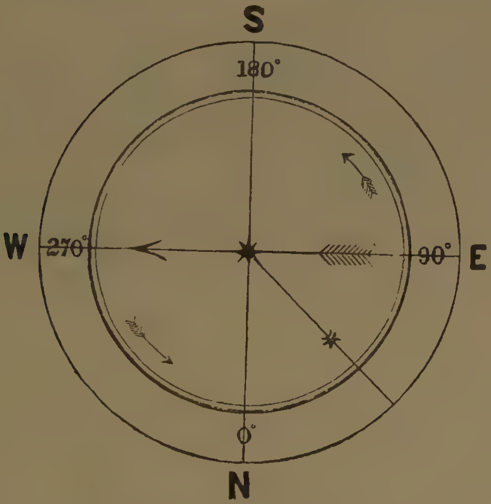

FIG. 192.—Measurement of Position Angle of a Double Star.

The periods of a few of these stars are as follows :—

Star.	Length of Period.
Lalande, 9,091	5·5 years
Zeta (ζ) Hercules	34·6 „
Alpha (α) Canis Majoris	49·4 „

Star.	Length of period.
Alpha (α) Centauri	85·0 ,,
70 Ophinchi	92·8 ,,
Gamma (γ) Virginis	175·0 ,,
Eta (η) Cassiopeiæ	222·4 ,,
Gamma (γ) Leonis	407·0 ,,
61 Cygni	415·1 ,,
Alpha (α) Geminorum	1001·2 ,,
Zeta (ζ) Aquarii	1578·3 ,,

Dimensions of Double Star Orbits.—The distance in miles between the components of a double star can be found if the parallax of the binary and the angular dimensions of the semi-major axis of the orbit are known. The relation between the parallax (see p. 434) of a body and its apparent size (see p. 450) is used in this determination.

Remembering that an astronomical unit is the distance of the earth from the sun, we have for binary stars the relation

$$\text{Number of astronomical units between components of binary} = \frac{\text{Angular semi-major axis of orbit}}{\text{parallax of binary.}}$$

Applying this principle to the star Eta (η) Cassiopeiæ, the distance between the components is found to be nearly sixty times the earth's distance from the sun. The components of Alpha (α) Centauri are separated by about twenty times the sun's distance.

Masses of some Binary Stars.—Whether binary stars revolve round one another under the influence of the law of gravitation cannot be actually proved, though there is presumptive evidence that such is the case. Assuming that the law holds good in interstellar space, the mass of a binary star can be determined when the size of the orbit in astronomical units or in miles is known. Each star actually revolves in an orbit round the common centre of gravity of the two, but in dealing with double star orbits it is usual to consider the brightest star as fixed and with a mass equal to the joint mass of the binary. The size of its orbit and the double star's period enable the fall of the stellar satellite to its primary to be determined, the calculation being the same as that applied to the case of the fall of the moon towards the earth (see p. 322). The fall per second which would take place if the stars were separated by the distance of the earth from the sun can then be found, and a comparison of the two results gives the relation of the mass of the binary to the mass of the sun. Here are the numbers obtained for three binary stars, of which the parallaxes have been determined.

Binary.	Parallax.	Mass in Terms of the Sun's Mass.
Alpha (α) Centauri	0″·80	1·8
Eta (η) Cassiopeiæ	0″·15	8·3
70 Ophinchi	0″·17	2·5

We thus find that Alpha (α) Centauri, a binary star of the first magnitude, has a mass nearly double the mass of the sun, while the Star Eta (η) Cassiopeiæ, which is much fainter, being of the fourth magnitude, has a mass eight times greater than the sun's mass.

Sirius and its faint Companion.—Careful observations of the position of Sirius showed, about 40 years ago, that the star described a *minute* orbit on the celestial sphere in about 50 years. In 1862, the late Mr. Alvan Clark discovered a very faint star near Sirius, and further observations have shown that the two stars—the very bright one and the very faint one—

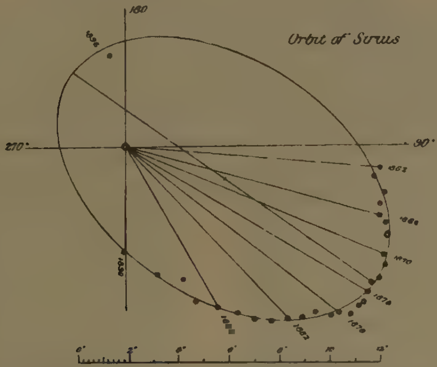

FIG. 193.—The Relative Positions of Sirius and its Companion in different Years, and the Orbit deduced from the Observations. From the *Monthly Notices of the Royal Astronomical Society.*

are physically connected and move around their common centre of gravity, just as do the moon and earth. From 1862 to 1896 the companion moved through 255°. (The relative positions in different years are shown in the accompanying figure.) The measurements of the positions of the companion with reference to Sirius and the angular distance between the two at different times have enabled the form of the orbit to be determined as is shown in the illustration (Fig. 193). The time of a complete revolution is found to be 52 years.

Clusters of Stars.—There are not only double stars and "double double" stars belonging to one another in the heavens, there are also many clusters of stars—groups in which stars can sometimes be counted in hundreds, all of them apparently in the same region and not merely in the same line of sight. The Pleiades is a well-known star group. An acute observer can count six bright stars in the group without telescopic aid. A small telescope will show about sixty in the same area of sky, and the photographic plate has registered the existence of more than a thousand.

In the constellation of Cancer a peculiar spot of misty light can be seen with the naked eye. An opera glass or a small telescope will resolve this nebulous spot into a cluster of forty or fifty stars, and a larger instrument will show hundreds of individual points of light clustered together. One of the finest star clusters in the heavens is in the constellation Hercules, and is known as 13 Messier, because it is No. 13 in a catalogue of star clusters compiled by an astronomer named Messier. This cluster looks like a small patch of haze to the unaided eye, but when a large telescope is used to observe it several thousand stars can be counted in the group. In the constellation of Perseus there is a fine double cluster of stars visible to the naked eye as a bright patch, and resolvable by a small telescope into two bee-like swarms of suns. The general appearance of some star clusters is illustrated in Fig. 194, but no picture of this kind can do justice to the splendid sight afforded by a good star cluster seen through a telescope of moderate dimensions.

The Milky Way.—An irregular band of faintly luminous appearance is seen stretching across the heavens on a fine night. This is the Milky Way or Galaxy, the nature of which

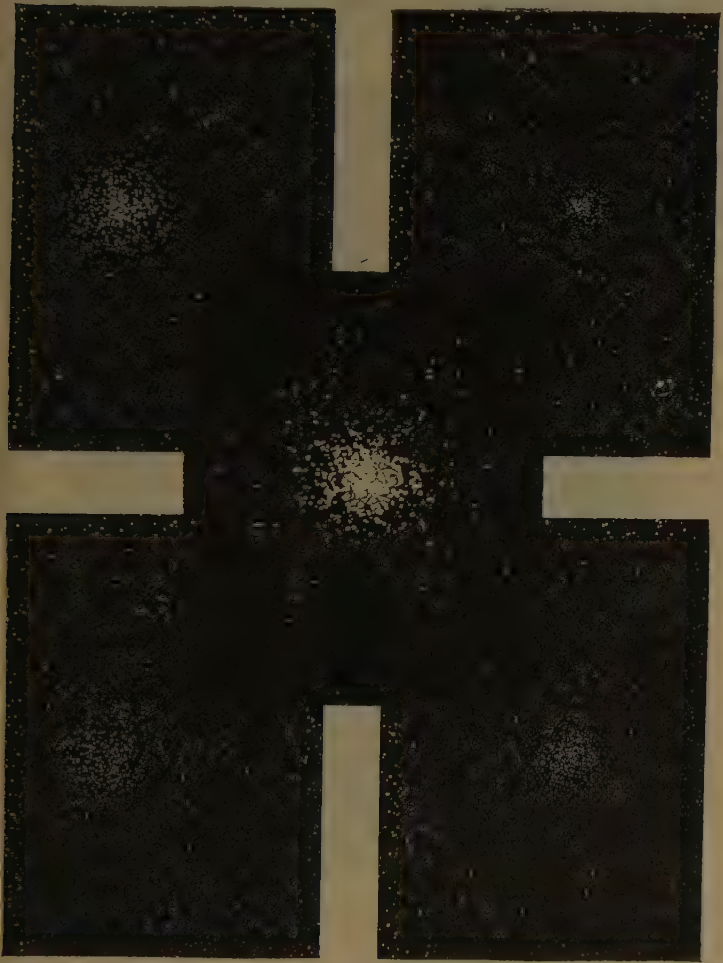

FIG. 194.—Star Clusters. With the exception of the Central Picture, which is from a Photograph of the Great Cluster in Hercules, the Clusters are from Photographs by Dr. Isaac Roberts reproduced in *Knowledge*.

formed a fruitful subject of speculation for early astronomers. When Galileo turned his small telescope upon it, however, he

FIG. 195.—A Portion of the Milky Way, with a Star Cluster in the Centre. (From a Photograph by Dr. Max Wolf.)

found that it really consisted of immeasurable small stars. "By the irrefragable evidence of our eye," he said, "we are forced from wordy disputes upon this subject, for the Galaxy is nothing else but a mass of innumerable stars planted together in clusters. Upon whatever part of it you direct the telescope, straightway a vast crowd of stars presents itself to view; many of them are tolerably large and extremely bright, but the number of smaller ones is quite beyond determination" (Fig. 195). It is estimated that 90 per cent. of the whole number of stars observable in the heavens are contained within a band bordered by the edges of the Milky Way. The majority of star clusters also lie in or near that zone. As we pass from the Milky Way, the average number of stars in the field of view of any telescope becomes less and is least when we arrive at the poles of the galactic circle.

Nebulæ.—The telescope has shown that the Milky Way is not a band of luminous mist but an immense number of small stars; it has shown also that certain peculiar luminous patches upon the sky are really stars clustered together. It might, therefore, be assumed that every celestial object of a similar misty character is composed of numerous stars packed so closely together that their individuality is lost and nothing but a general patch of luminosity is seen. This was the view of astronomers about 30 years ago. It was thought that, given a sufficiently powerful telescope, every patch of mist upon the sky would be resolved into stars. We now know that this view is incorrect; there are upon the heavens many faint patches and wisps of luminous haze which can never be broken up into stars, and they are termed *nebulæ*. About 8,000 of these irresolvable objects are known, but their light is so feeble that only two—the Great Nebula in Orion and the Great Nebula in Andromeda—can be distinguished with the naked eye. It is remarkable that nebulae are least numerous near the Milky Way and most numerous at a distance from that zone, their distribution being thus just the reverse of the distribution of stars and star clusters.

Spectroscopic Difference between Stars and Nebulæ.—The true nature of nebulæ was discovered by Dr. (now Sir William) Huggins in 1864 by means of a spectroscope attached to a telescope. It is beyond the province of physiography at this stage to enter into the details of spectrum analysis. Suffice it to say here that the vapours of different substances emit, when at a sufficiently high temperature, light of different qualities, and that a glass prism acts as a sieve upon a beam of composite light and splits it up into component parts. The light from many substances may be represented in such a beam, but the prism is able to sort them all out, so that by observing the arrangement of the various qualities of light after it has passed through a prism, it is possible to determine what substances are contributing their emissions to the composite beam.

A spectroscope (Fig. 196) consists essentially of one or more prisms, P, with an arrangement, C, for limiting the breadth of the beam and making the rays parallel, and a small telescope, T, for viewing the analysed light. When such an instrument is fitted upon a telescope and the telescope is directed towards the sun, a rainbow-coloured band having numerous dark lines at right angles to its length are observed. These lines are the representatives of substances whose luminous vapours exist in the sun, and by identifying them with lines produced by burning terrestrial substances, the materials of which the sun is composed have been found. The same principle applies to the stars. When most stars are observed through a spectroscope fitted to a telescope, dark lines, in some cases identical with the sun lines, are observed crossing a coloured strip. When, however, a true nebula is observed in the same way, bright lines instead of dark ones are seen. A distinct difference is thus found to exist between ordinary stars and

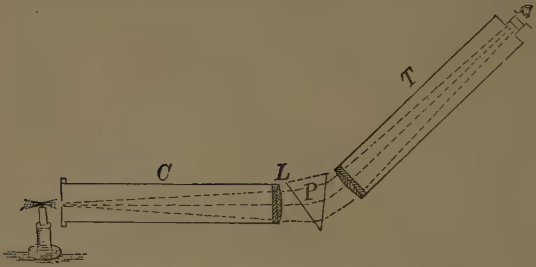

FIG. 196.—Diagram to show the Parts of a simple spectroscope. *C*, Collimator with a Lens *L* to make the Rays from the Lamp fall in a Parallel beam upon the Prism *P*. The small Telescope *T*, is used to observe the Decomposed Light.

nebulæ, when their light is analysed. Most stars, like the sun, consist of an incandescent nucleus surrounded by a cooler atmosphere which produces the dark lines observed with the spectroscope. The fact that only bright lines are seen in the analysed light of a nebula shows that each misty patch upon the heavens consists of glowing vapours. Hydrogen is prominent as a glowing gas in every nebula, but the nature of the other materials represented in nebular light is doubtful.

Nature of Nebulæ.—It must not be concluded, however, that nebulæ are nothing but masses of gas. Sir Norman Lockyer has brought forward a large amount of evidence to show that a nebula is a swarm of little rocks (meteorites), which batter against one another, and develop so much heat in the collisions that some of the constituents are driven into vapour and rendered luminous. His definition of a nebula is as follows: "A true nebula consists of a sparse swarm of meteorites, the luminosity of which is due to the heat produced by collisions. The interspaces are partly filled with hydrogen and magnesium, and other vapours which are volatilised out of the meteorites."

Forms of Nebulæ.—The forms of nebulæ differ very considerably; nevertheless they may be classified, though the classification will not include every variety any more than the classes into which clouds are grouped include every form of cloud. Five classes of nebulæ may be recognised, viz.: (1.) Irregular nebulæ. (2.) Ring nebulæ, and elliptical nebulæ. (3.) Spiral or whirlpool nebulæ. (4.) Planetary nebulæ. (5.) Nebulæ surrounding stars. The great nebula in Orion (Fig. 197 *a*) is a good example of an irregular nebula. The larger masses of nebulosity are, as a rule, irregular in form. An exception to the rule is, however, the great nebula in Andromeda (Fig. 197 *b*). This evidently belongs to the class of elliptical nebulæ. In all probability the curved streams of nebulosity surrounding the nucleus are nearly circular in form, and they appear elliptical because they are inclined to us. An elliptical nebula is thus a ring or annular nebula seen slantingly. The majority of the smaller nebulæ are more or less spindle-shaped, like the Andromeda nebula. A ring nebula—that in the constellation of Lyra, is illustrated in Fig. 197 *c*. The plane of the nebulous ring seems here to be almost at right angles to our line of sight. A magnificent spiral or

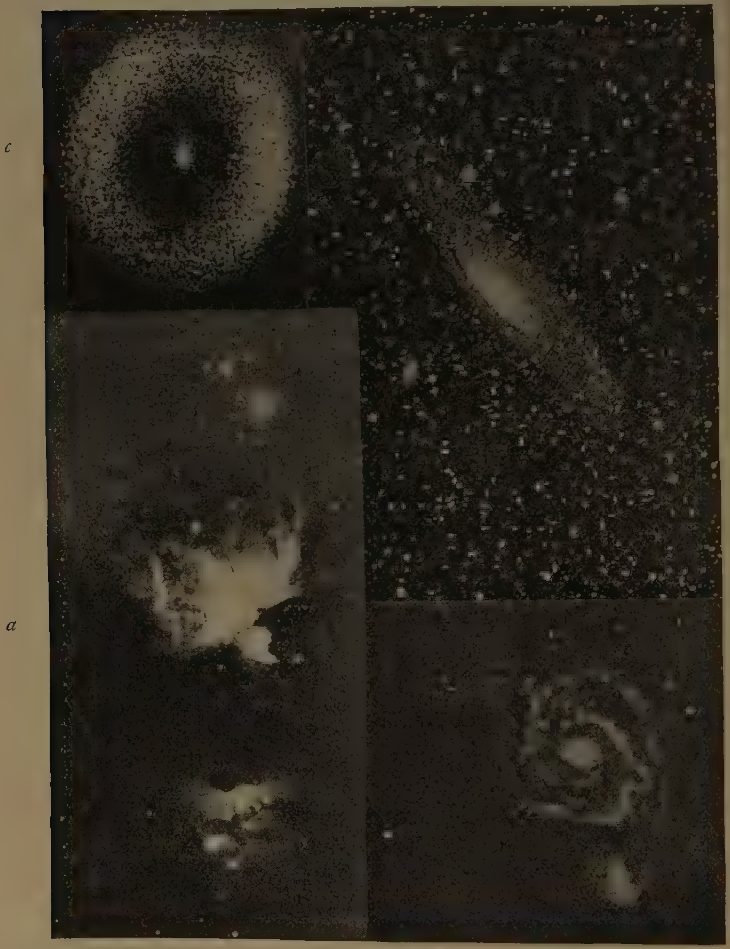

FIG. 197.—Forms of Nebulæ, reproduced from Photographs. *a*, Nebula of Orion; *b*, Elliptical Nebula of Andromeda; *c*, Ring Nebula of Lyra; *d*, Spiral Nebula of Canes Venatica.

whirlpool nebula occurs in Canes Venatici, and is represented in Fig. 197 *d*. Planetary nebulæ are nearly circular patches of luminosity of uniform brightness. Nebulous stars are somewhat similar in appearance to planetary nebulæ but differ from them by the presence of a bright nucleus, this looking like a "star shining through fog."

Connection between Stars and Nebulæ.—There are about fifty objects in the heavens which look like stars when observed with a telescope, but which show the characteristic bright lines of nebulæ when their light is analysed with the spectroscope. These objects probably represent a transition stage between an irregular nebula and an ordinary star with an absorbing atmosphere. It is believed that nebulæ gradually condense into stars—that, in fact, the principle of evolution may be applied to celestial bodies as it is applied in the organic kingdom. The naturalist finds it difficult to draw the line between different groups of organisms, and, in the same way, stars of various types merge into one another and into nebulæ so imperceptibly that the astronomer sometimes cannot distinguish the differences between them.

Mr. R. A. Gregory has thus described this evolution of celestial bodies[1]: "Stars are believed to be evolved from nebulæ, and as they grow old to change their quality of light, the spectroscope thus confirming the conclusion arrived at by Sir William Herschel from a study of the telescopic appearance of celestial objects. He found planetary nebulæ merging into nebulous stars, stars surrounded with a large amount of nebulosity, and others possessing but a small hazy mist or halo. Double nebulæ appeared to form double stars, and large masses of nebulosity to break up into star clusters. In no one case could this development be traced; but Herschel's observations showed that the finished star and nebulæ are connected by such intermediate steps as to make it highly probable that every succeeding state of the nebulous matter is the result of the action of gravitation upon it, while in the preceding one; and by such steps irregular nebulosities are brought up to the condition of planetary nebulæ, from which it passes to a nebulous star, and then to the completed product."

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[1] *Vault of Heaven*, p. 157. Methuen and Co.

CHIEF POINTS OF CHAPTER XIX.

Double Stars are stars which appear to be single when seen with the naked eye or a small telescope, but can be separated into two or more stars when viewed with more powerful optical aid. Optical doubles are stars in accidental juxtaposition near the same line of sight, and physical doubles or binary stars are those which are in revolution round one another.

The Parallel Wire Micrometer is used to measure small angular distances, *e.g.* the angular distance between the components of a double star. It consists essentially of two parallel wires capable of being brought together or expanded by turning a screw. The angle represented by one turn of the screw having been determined by a preliminary observation, the angle represented by any number of turns, or fractions of a turn, is known. By observing how many turns the screw has to make in order to separate the parallel wires to any desired extent, the angular separation of the wires can be deduced.

The Position Circle is really a part of the micrometer, and is used to determine directions upon the sky, *e.g.* the direction of the line joining the two components of a double star.

The Orbits of Double Stars are determined by making measures for several years of the distance between the components of binaries, and the direction of the line connecting them. Both the distance and direction of the components will be found to change gradually, and from these changes the apparent orbit is found. In this way, binary stars have been found revolving round one another in periods ranging from 5·5 years to 1,578 years.

Star Clusters consist of a large number of stars close to one another, like a swarm of bees. To the naked eye a large star cluster looks like an undefined luminous patch, but a telescope separates it into its individual points of light.

The Milky Way is an irregular luminous belt surrounding the heavens, and consisting of innumerable small stars.

A Nebula looks like a distant star cluster, and it used to be thought that all nebulæ could be resolved into stars by using sufficiently powerful telescopes. This view is incorrect. The spectroscope has proved that nebulæ consist of masses of glowing gas (possibly produced by collisions of meteoritic particles), and not of collections of stars.

Forms of Nebulæ.—From an examination of his photographs, Dr. Isaac Roberts divides nebulæ into the following classes:—(1) vast areas of cloud-like matter; gaseous, and probably of discrete solid particles intermixed; (2) smaller areas of matter undergoing the process of condensation and segregation into more regular forms; (3) spiral nebulæ in various stages of condensation and of segregation; (4) elliptic nebulæ; (5) globular nebulæ.

QUESTIONS ON CHAPTER XIX.

(1) State what you know about nebulæ.

(2) State what is known concerning the nature and constitution of nebulæ.

(3) Describe a parallel wire micrometer, and state how you would use it to determine the angular distance between the two components of a double star.

(4) What is a binary star? How can stars which are only optical doubles be distinguished from those which are physical doubles?

(5) Describe the principle underlying the use of a parallel wire micrometer to measure small angles.

(6) State what you know about the orbits of double stars.

(7) Describe briefly the history of the discovery of the companion to Sirius

(8) What is a star cluster, and how can a nebula be distinguished from it?

(9) State the principal differences between star clusters and nebulæ.

(10) Describe the nature of the Milky Way, and state how star clusters and nebulæ are distributed with reference to it.

(11) Nebulæ were formerly supposed to be distinct star clusters. What are the grounds for this view, and how has the view been found to be untenable?

(12) Mention some similarities and differences between stars and nebulæ.

(13) Into what classes may nebulæ be divided according to their forms?

CHAPTER XX

THE UNIVERSE

CELESTIAL MEASUREMENTS

Meaning of Parallax.—In astronomy, parallax is defined as "the difference between the directions of a heavenly body as seen by the observer and as seen from some standard point of reference" (Young). A simple experiment will make this definition clear.

EXPT. 42.—Take a lath, say a yard long, and place it upon a table, on which also some object is placed at a distance. From each end of this lath point another lath towards the object, and rule two lines on pieces of paper placed between them to show the inclination of the two pointers to the first lath. Make on the blackboard a line to represent the yard lath, and at each end of it draw the angles obtained above and produce the lines to meet. The intersection of these lines represents the position of the object, and its distance measured on the same scale as the line representing the yard lath will give us the distance of the object.

Or the experiment may be varied a little in the following way :—

EXPT. 43.—Procure a lath about a yard long, and bind one leg of a pair of compasses or dividers at each end. Place the lath upon a table and point the free leg at each end to some object about two or three yards away in the room. Measure the angle between the leg and the lath at each end. Repeat the experiment by pointing the lath at an object at the far end of the room. Then take the lath outdoors and point the free legs to a very distant object. It will be found that the greater the distance of the object pointed at, the greater is the angle between the lath and the free compass leg at each end ; in other words, the legs become more and more nearly parallel as the distance of the object observed increases. (Fig. 198.)

Now we know from Euclid (I. 32) that if the three angles of any triangle be added together, the sum obtained is always equal to 180°; so that if two of the angles are known, the third or remaining angle can be found by subtracting the sum of the two known angles from 180°.

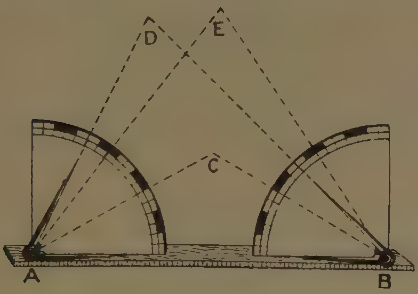

FIG. 198.—An instrument to illustrate Parallax.

In the preceding experiments two angles (A and B) of a triangle were measured in the case of each object observed. To find the remaining angle, ACB for instance (Fig. 198), we have the relation

$$\text{Angle } ACB = 180^\circ - (BAC + ABC),$$

or, in the other cases,

$$\text{Angle } ADB = 180^\circ - (BAD + ABD)$$
$$\text{Angle } AEB = 180^\circ - (BAE + ABE).$$

The angles ACB, ADB, AEB, thus deducted from the observations, represent the parallax of the objects at C, D, and E respectively. It will be seen from this that the nearest object has the greatest parallax, and the most distant has the smallest parallax.

The application of these considerations to celestial bodies will be immediately understood. If two astronomers on opposite sides of the earth point their telescopes at the moon, their instruments may be compared with the two compass legs at the ends of the lath in Expt. 43, and the diameter of the earth to the length of the lath; while the object, instead of being terrestrial, is celestial. Evidently the operations are similar in every respect. The astronomers would be able, by the method given above, to deduce from their measurements the magnitude of the angle between the directions of the two telescopes. The details and difficulties involved in this determination need not be described here. It will be sufficient for the student to know the principle, which is identical with that of Expt. 43.

The angle between the two directions in the case of the moon is nearly two degrees (2°). This, then, is approximately the angle between two lines drawn from the centre of the moon to opposite sides of the earth. One-half this angle, that is, *the angular semi-diameter of the earth as viewed from the moon, is the moon's parallax.* The moon's parallax is nearly 1° (exactly 57′ 2″), which is by far the greatest parallax of any celestial body. The sun's parallax is only 8″·8, that is to say, two lines drawn from the sun, one to the earth's centre and the other to a point on the earth's equator, would contain an angle so small as 8″·8, whereas, in the case of the moon the angle is 57′ 2″. This fact is of itself enough to demonstrate the much greater distance of the sun from the earth than the moon.

Relative Distances.—The relative distances of the planets from the earth and sun were determined with fair accuracy before the perfection of astronomical instruments made it possible to state the actual distances in miles. Thus, if the ratio of the distance of the earth from the sun compared with that of Venus be required, the question can be solved by the following considerations. In Fig. 199, let E represent the earth, S the sun, and V′, V, Venus at its greatest eastern and western elongations. Then SVE and SV′E may be regarded as right-angled triangles, and in such triangles, we must remind the reader, the ratios $\frac{SV}{SE}$ and $\frac{SV'}{SE}$ are each known as the *sine* of the angles SEV and SEV′ respectively, and we can write :—

$$\frac{SV}{SE} = \text{sine SEV} ; \frac{SV'}{SE} = \text{sine SEV}'.$$

The angle SEV, that is, the angular distance of Venus from the sun at the greatest elongation, is about 47°. Hence we have from the above equation—

$$\frac{\text{Distance of Venus from sun}}{\text{Distance of earth from sun}} = \frac{SV}{SE} = \text{sine SEV} = \text{sine } 47^\circ = 0{\cdot}71.$$

Consequently we have a proportion which we can write in two ways :—

Earth's distance from sun : Venus's distance from sun = 1 : 0·71 ; or,

$$\frac{\text{Earth's distance from sun}}{\text{Venus's distance from sun}} = \frac{1}{0{\cdot}71}.$$

In Fig. 200 the case of a superior planet is represented, but the determination of the ratio between its distance from the sun compared with that of the earth is not so simple. Let M represent the planet Mars in opposition, and M′ its position several weeks later. Its angular distance from the sun, or, as we have learnt to call it, its elongation, is observed in the position M′. Between one occurrence of an opposition of Mars and the next—an interval which is called the planet's *synodic period* —(see p. 316), the angle M′SE gradually increases from 0° to 360°. If we assume this increase to be regular, we can say the angle M′SE is the same fraction of 360° that the interval between the two positions of Mars represented in the illustration is of a complete synodic period.

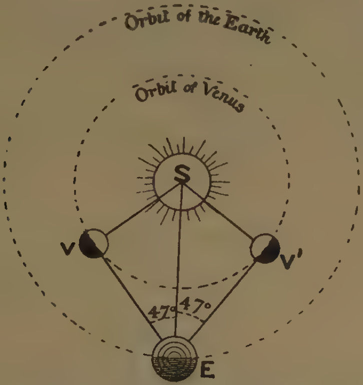

FIG. 199. Determination of the Distance of Venus by Observation at greatest Elongation.

The angle SEM′ is the elongation observed when Mars is in the position M′ ; and the angle M′SE is known from the above considerations; consequently the angle SM′E can be obtained by subtracting the sum of the other two from 180° (p. 435). An easy application of trigonometry enables us to determine the length of the sides of the triangle from the three angles. We may write—

$$\frac{\text{Distance of Mars from sun}}{\text{Distance of earth from sun}} = \frac{\text{sine SEM}'}{\text{sine SM}'\text{E}}.$$

Distance of the Earth from the Sun.—The velocity with which light waves travel has been determined in several ways, which are briefly described in Chapter IV. The result of these experiments gives this velocity as 186,330 miles per second. Knowing this, the observations, first made by the Danish astronomer, Roemer, upon the moons of the planet Jupiter, provide us with the means of determining the sun's distance from us.

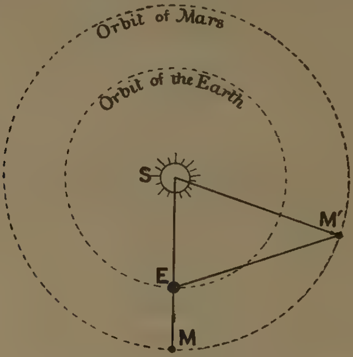

FIG. 200.—To illustrate a method of determining the relative distances of Mars and the Earth from the Sun.

Careful observations show that the journey across the earth's orbit is completed by light travelling at the rate of 186,330 miles a second in 16 minutes, 38 seconds, or 998 seconds; and consequently the time taken by light to traverse half this distance, which in the radius of the earth's orbit is 499 seconds. The length of the radius in miles, in other words the sun's mean distance, is therefore 186,330 × 499 = 92,978,670 miles, or roughly 93,000,000 miles.

It is worth while to point out that the degree of accuracy obtainable by this method depends upon that of the value taken for the velocity of light; the more correct our value for this quantity, the nearer the truth will our result for the sun's distance be.

Sun's Distance determined from the Aberration of Light. — The student has previously learnt (p. 70) how the velocity of light can be determined by laboratory measurements and other methods, and also how the constant of aberration is measured by observations of the displacements of stars. It is easy, by combining these two numbers, to calculate the velocity of the earth in its orbit. Knowing this velocity we can immediately deduce the number of miles traversed by the earth in a sidereal year which will evidently be the circumference of the earth's orbit. From this value for the orbit's circumference we can calculate its diameter and radius. The radius, which is clearly the sun's distance from the earth, can in this way be determined from the constant of aberration. We have seen on page 297 that

$$\frac{\text{Velocity of earth}}{\text{Velocity of light}} = \text{tangent (p. 297) of angle of aberration}$$

$$\begin{aligned}\text{or velocity of earth} &= \text{velocity of light} \times \tan 20''{\cdot}49\\ &= 186{,}330 \times \tan 20''{\cdot}49\\ &= 10{,}089.\end{aligned}$$

That is to say, light travels 10,089 times faster than the earth. If the earth moved with the same velocity as light it would complete a single revolution round the sun in

$$\frac{365{\cdot}25 \text{ days}}{10089} = 52 \text{ minutes } 6 \text{ seconds},$$

and would perform a journey along a radius of the orbit at the same rate in 8 minutes 19 seconds, or 499 seconds. It is clear, therefore, that the distance of the sun is $499 \times 186{,}330 = 92{,}978{,}670$ miles. It should be noted again that the value of the velocity of light taken in the above calculation materially affects the value of the sun's distance. The value we have used is at present regarded as fairly accurate.

Determination of Sun's Distance by Observations of Mars at Opposition.—The actual observation which is made is that of the parallax of Mars, and from this result the distance of Mars *from the earth* can be calculated. Knowing the sidereal periods (p. 292) of Mars and the earth, it is at once possible by Kepler's third law (p. 326) to determine the ratio of the distances of Mars and the earth from the sun. Then, we reason as follows:—the distance EM (Fig. 201) is determined by observations, as above, at an opposition; and the ratio of SE to SM is found by Kepler's third law. Evidently SE, the distance of the earth from the sun, is equal to SM − EM. Suppose we assume that SE is 10, then from the application of Kepler's law we should find SM = 16, and clearly EM = 16 − 10 = 6. We can therefore write—

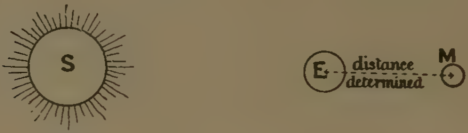

FIG. 201.—To illustrate how the Determination of the distance of Mars enables the Sun's distance to be found.

$$\frac{\text{Distance of earth from Mars}}{\text{Distance of earth from sun}} = \frac{6}{10} = \frac{3}{5}.$$

The parallax of Mars at opposition is roughly 14″, and we have seen that the parallax of a body is inversely proportional to its distance from the observer; and, therefore, using the above ratio we obtain—

$$\frac{\text{Parallax of sun}}{\text{Parallax of Mars}} = \frac{3}{5}.$$

Therefore,

$$\text{Solar parallax} = \frac{3}{5} \times 14'' = 8''\cdot 4.$$

Such is the principle of the determination of solar parallax from observations of Mars at an opposition. There are two plans adopted in making the actual determination: either the planet may be observed from two stations on or near the same meridian, but situated respectively north and south of the equator, *e.g.* at Greenwich and the Cape; or its position with reference to fixed stars in the neighbourhood may be determined shortly after rising and again shortly before setting.

The Meridian Method.—The first of the ways mentioned termed the meridian method, is the same as that used in determining the distance of the moon, and we shall exemplify the method by reference to the moon. In Fig. 202 E is the centre of a circle which represents the earth, M is the moon, and the parallel lines from S, S, are rays of light from a star whose great distance, compared with the earth's diameter, makes the assumption of their being parallel quite free from error. *G* stands for the observatory at Greenwich, and *C* for that at the Cape. The line EGʒ gives the direction of the zenith at Greenwich, and ECʒ′ the same direction for the Cape observatory. The continuation of the earth's axis in both directions marks out the celestial poles.

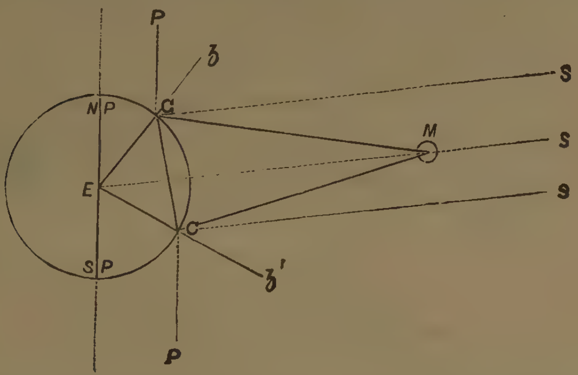

Fig. 202.—Determination of the Moon's distance by the Meridian method.

The observer at Greenwich measures the angle PGM, which is the north polar distance of the moon at Greenwich; the observer at the Cape measures the angle PCM, the south polar distance of the moon at his place of observation. Similarly, the angles PGS and PCS are the north and south polar distances of the star at the two places on the earth's surface; and because SC and SG are parallel, as well as the two lines marking the directions of the celestial poles at the observatories, the north polar distance of the star at Greenwich and the south polar distance at the Cape, added together, make exactly 180°. But the north polar distance of the moon at Greenwich is greater than the north polar distance of the star at the same place, and at the Cape the south polar distance of the moon is similarly greater than that of the star, consequently the sum of the N. P. D. of the moon at Greenwich and its S. P. D. at the Cape is considerably greater than 180°. We are able to ascertain how much greater by an easy application of Euclid. Since SG is parallel to SE, and GM meets them, the angle SGM is equal to its alternate angle GME (I. 29). Similarly the angle EMC is equal to SCM. Therefore SGM + SCM = amount the sum of the polar distances exceeds 180° = GMC. This angle GMC is the "parallactic" angle subtended by the line GC joining the places of observation; its value has been found to be about 1°·5.

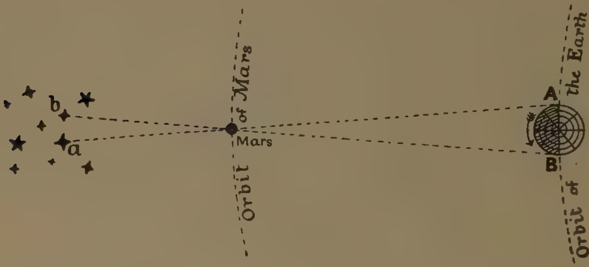

FIG. 203.—Diurnal Method of Determining the Parallax of Mars.

The determination of EM, the distance of the moon from the earth's centre, is now simply the solution of the triangle EGM. The angle GME is known by the above observation; the angle MEG is the latitude of Greenwich Observatory; the line EG is the radius of the earth. These three being known, we can by trigonometry find the length of EM.

The Diurnal Method.—In Fig. 203 the earth is supposed to be viewed from the north pole of the heavens, and consequently the circle will represent the earth's equator, and the points A and B are situated upon it. When rising, Mars would be seen in the direction AM*a* to an observer at A; and when setting, the earth in the meantime having rotated so that the observer originally at A is now at B, Mars will appear along the direction BM*b*. The angular displacement *a*M*b* is evidently due to the change of position from A to B, for the planet's own motion in the interval between the two observations can be allowed for. A and B being on the equator, AB is nearly 8,000 miles in length. By Euclid I. 15, the angle AMB is equal to the angle *a*M*b*, and the angle AMB is the angle which the earth's diameter subtends at Mars, and a half this is therefore the angle which the earth's radius subtends at Mars, *i.e.* the parallax (p. 436). It has already been explained how the distance of the earth from the sun can be found when the parallax of Mars is known.

Some of the asteroids can be used in the same way when in opposition. The parallax of the particular asteroid under observation is determined by either of the above methods, and from the result the solar parallax is deduced in the manner already described for Mars.

Determination of the Distance of the Sun by Observations of a Transit of Venus.—The transits of Venus (p. 359) are utilised for determining the distance of the planet from the earth, as well as to indirectly determine the sun's distance. The methods of observation are :—

1. The times of the beginning and end of the transit may be observed from places having different longitudes.

2. The position of the shadow of Venus upon the sun's disc may be observed simultaneously at two or more stations as far apart as possible, or photographs may be taken from different stations, and the displacement due to difference of position may be subsequently determined by measurements of the photographs.

First Method.—In Fig. 204 we are supposed to be looking down upon the sun, the earth, and Venus from the north celestial pole. A and B are two stations on or near the earth's equator, and we will suppose them separated by the length of the earth's diameter. An observer at A sees Venus come into apparent contact with the sun's edge when the planet is at the position *a* on its orbit. When about 11·5 minutes later, Venus reaches the position *b* on its orbit, an observer at B sees the apparent contact of the planet with the sun's edge. Moreover, the angles *b*V*a* and BVA are identical. Taking AB as a diameter of the earth, the angle AVB is the angle which the earth's diameter subtends at the sun, and it is consequently twice the solar parallax.

It is required now to know the angle through which Venus moves relatively to the earth and sun in a second or minute, for we can then find what angle Venus would move through in the observed interval between the times of contact as seen from A and B.

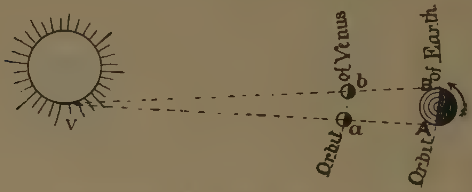

FIG. 204.—Determination of the Sun's distance by Observations of a Transit of Venus.

Venus goes round the sun and catches up to the earth again in 584 days—that is, the planet gains 360° on the earth in 584 days. This rate of relative angular motion of Venus works out at about 37 minutes per day, or 1·54 seconds per minute, for $\frac{360 \times 60 \times 60}{584 \times 24 \times 60} = 1{\cdot}54$. The interval between the contacts observed at A and B would be 11 minutes 30 seconds; so that the angle *aVb* (and therefore also AVB) equals 11 minutes 30 seconds × 1·54 seconds of arc = 17″·7. Hence one half this, that is the angle which the earth's radius subtends at the sun, = 8″·8 = solar parallax.

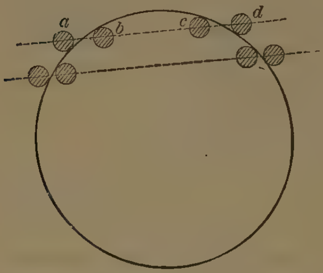

FIG. 205.—Apparent Paths of Venus across the Sun during a transit observed from different stations. The upper path is that seen from a southern station; the lower is that seen from a northern station, but the distance between the paths is exaggerated.

To obtain the best result by this method, four contacts of the edges of Venus and the sun are observed, viz.:—

1. Western edge of planet with eastern edge of sun (first external contact).
2. Eastern edge of planet with eastern edge of sun (first internal contact).
3. Western edge of planet with western edge of sun (second internal contact).
4. Eastern edge of planet with western edge of sun (second external contact).

These contacts are marked *a*, *b*, *c*, *d* in Fig. 205.

Second Method.—Just as in determining the distance of the moon (p. 441) two stations were chosen as far apart as possible, one in the northern hemisphere and one in the southern, so in this method two stations similarly situated are selected. To an observer in the northern hemisphere at the moment of the transit Venus will appear to be projected upon a different part of the sun's disc to that where it will appear to be to the observer in the southern hemisphere. The planet will seem lower to the northern observer. In Fig. 206 C and G represent the positions Venus appears to have to the southern and northern astronomers respectively. The interval between C and G is much exaggerated.

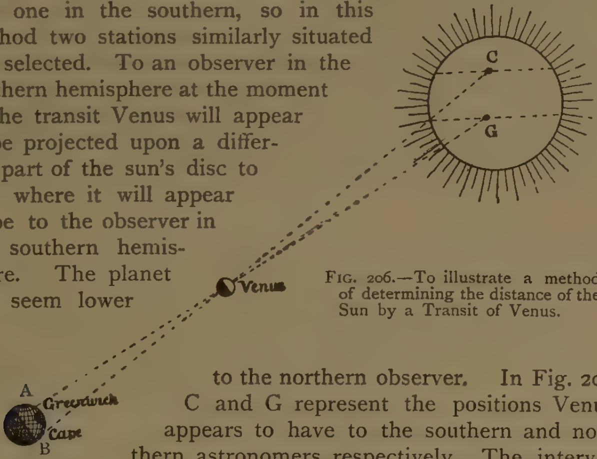

FIG. 206.—To illustrate a method of determining the distance of the Sun by a Transit of Venus.

The angle which it is required to measure is CVG, or the equal vertically opposite angle A V B. We know that—

$$\frac{\text{Distance of Venus from earth}}{\text{Distance of Venus from sun}} = \frac{\text{A B}}{\text{C G}}.$$

To find the angular value of CVG we ascertain the fraction CG is of the sun's angular diameter, which is known. This gives us the value of the angle C V G, and consequently of A V B. If we suppose A and B to be at the north and south poles of the earth then we know that a half of the angle A V B is the parallax of Venus. From Kepler's third law and the measured parallax we can determine the sun's parallax as in the case of Mars.

Prof. William Harkness[1] has discussed the whole of the observations which have been made to determine the sun's distance, giving due weight to the methods employed. His conclusion is as follows:—"With almost any possible system of weight the solar parallax will come out very nearly 8″·809 ± 0″·0057, whence we have for the mean distance between the earth and the sun 92,797,000 miles, with a probable error of only 59,700 miles; and for the diameter of the solar system, measured to its outermost member, the planet Neptune, 5,578,400,000 miles."

Stellar Parallax.—So far we have only referred to what is known as geocentric parallax, which, as has been explained, is the angle which the earth's equatorial radius subtends at the sun or moon. In the case of these luminaries and of other bodies in the solar system, this parallax can be deduced from measures made at widely removed stations on the earth's surface; but the distances of the stars are so immense and the earth is so small in comparison with them, that even with the most perfect instruments now in use no difference of direction could by any possibility be detected between two lines drawn from opposite sides of the earth to any star. Indeed, so far removed are the stars from us that the diameter of the earth's orbit round the sun—twice ninety-three millions of miles—is an insignificant length in comparison with their distances. Only in the case of a few stars can any difference of direction be detected when they are observed at the extremities of this great base-line of 186,000,000 of miles; the majority of stars yet observed show no appreciable parallax.

The Parallax of a Star is the Angle subtended at the Star by the Semi-Major Axis of the Earth's Orbit.—It has already been explained that stellar parallaxes are so small, and the distances of stars are consequently so tremendous, that the distances in miles convey no real impression to the mind. A better way is to state how long light, travelling as it does at an approximate rate of 186,000 miles a second, would take to journey from a star to the earth. A "light-year" is the distance (about six billions of miles) light would travel in a year. A parallax of 1″ is equivalent to 3·26 light-years, whence it follows that the distance of a star in light-years is obtained by dividing 3·26 by the parallax in seconds of arc. The parallaxes of six stars and the corresponding distances in light-years are here given.

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[1] *The Solar Parallax and its Related Contents.* Washington: Government Printing Office, 1891.

Designation of Star	Magnitude	Parallax	Distance in Light-Years
α Centauri	0·5	0″·75	4·3
Sirius	1·5	0·39	8·3
Procyon	0·5	0·26	12·5
Altair	1·0	0·20	16·3
Arcturus	1·0	0·13	25·0
Vega	0·2	0·12	27·1

It happens that the number expressing a star's distance in light-years denotes also the distance of the star in miles upon a scale of one inch to represent the earth's distance from the sun.

Methods of determining Stellar Parallax.—Two methods have been employed in the determination of stellar parallax, viz., (1) the absolute method; (2) the differential method.

The Absolute Method.—This plan consists in making accurate observations of the right ascension (p. 282) and declination (p. 282) of a star throughout a

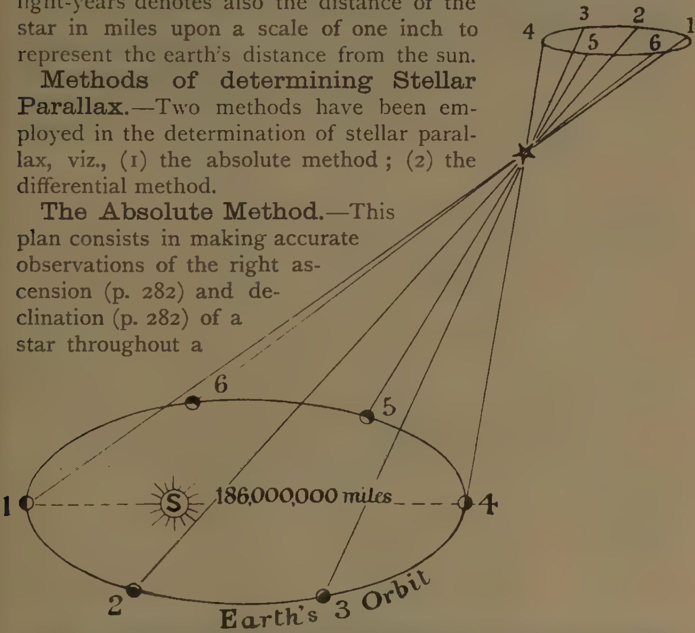

Fig. 207.—Parallactic Ellipse produced by the Earth's Orbital Motion. The lines show the direction in which a Star is seen from different points of the Earth's Orbit.

year by means either of a transit instrument or meridian circle. All known disturbing effects are eliminated as far as possible. These sources of error are very numerous, and include refraction, precession, nutation, aberration, proper motion, errors of adjustment of the instrument, and variations of the instrument according to the seasons. The small differences of right ascension and declination, which still remain after this multitude of allowances has been made, enable the parallax of the star to be determined (Fig. 207). The method is not a good one practically. The disturbing effects are so numerous and the corrections to be made are so large compared with the final quantity to be measured, that the result when obtained is of very little value.

The Differential Method.—The second method is very much more satisfactory, and there are none of the above corrections to be made. The method consists in measuring the relative positions of the selected star with reference to other fainter stars in its neighbourhood. It is assumed that the faintness of the stars in the proximity of the one under observation is due to their being at a much greater distance from the earth, so that it may be assumed that they have practically no parallax at all. Since by this method there is no determination of the exact position of the star under observation,

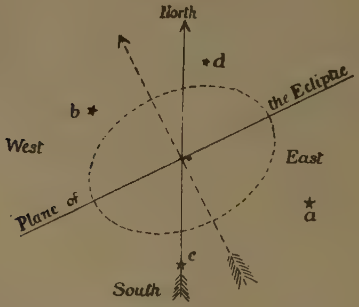

FIG. 208.—The small Star in the centre of the dotted Ellipse is one of the components of the Binary Stars 61 Cygni. The Ellipse shows the parallactic orbit of this Star, with reference to the four neighbouring faint Stars *a*, *b*, *c*, *d*, as shown by photographs taken at different times of the year.

but only its relative situation compared with other stars, the sources of error referred to in the previous paragraph are obviated. The late Prof. Pritchard, instead of actually noting down at the time of observation the relative position of a star compared with the near faint stars, took photographs at the intervals at which astronomers had been in the habit of making their direct observations. This plan gave a permanent record of the relative positions required, and eliminated all the errors of observation. The magnified parallactic orbit of one of the components of the double star 61 Cygni, determined in this way, is shown in Fig. 208.

Relation between Parallax and Distance.—If a halfpenny, which has a diameter of one inch, be viewed at a distance of 206,265 inches, that is about 3¼ miles, it is found to subtend an angle of one second of arc. Similarly any object viewed at a distance of 206,265 times its own length subtends an angle of one second of arc. By utilising this fact, it is possible to calculate the distance in miles of any celestial object when its parallax is known.

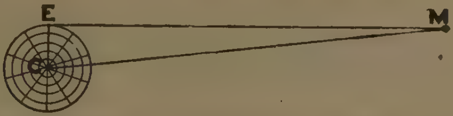

FIG. 209.—To illustrate the Relation between Parallax and Distance.

Fig. 209 shows the earth and moon supposed to be viewed from the north celestial pole, and consequently the parallax of the moon will be represented by the angle EMC, which is equal to 3,422 seconds of arc (57′ 2″). Now CE is the earth's equatorial radius, or 3,960 miles; therefore we have—

$$\frac{\text{Number of seconds of arc in the angle EMC}}{206{,}265} = \frac{\text{CE}}{\text{CM}}.$$

Therefore,

$$\frac{3{,}422}{206{,}265} = \frac{3{,}960}{\text{CM}} \text{ miles.}$$

Hence,

$$\begin{aligned}\text{CM} &= \frac{3{,}960 \times 206{,}265}{3{,}422},\\ &= 240{,}000 \text{ miles (nearly)}\\ &= \text{distance of moon.}\end{aligned}$$

Similarly to find the sun's distance in miles, knowing its parallax to be 8·8 seconds of arc, we have—

$$\frac{8{\cdot}8}{206{,}265} = \frac{3{,}960}{\text{Sun's distance}} \text{ miles}$$

$$\therefore \text{Sun's distance} = \frac{3{,}960 \times 206{,}265}{8{\cdot}8} \text{ miles}$$

$$= 92{,}800{,}000 \text{ miles (about).}$$

In the case of the stars, the semi-major axis of the earth's orbit instead of the earth's equatorial radius is the base line. But in either case the distance *d* of a celestial object in miles is given by the expression—

$$d = \frac{206{,}265}{\text{Parallax of object expressed in seconds of arc}} \times \text{Base line (expressed in miles).}$$

Let the earth's semi-major axis be represented by *a*, which will represent the distance known as the *astronomical unit.* It will approximately equal 93,000,000 miles. Then in the case of the star α Centauri, whose parallax is 0·75 second of arc, we can find its distance in the terms of the astronomical unit at once thus—

$$d = \frac{206{,}265}{0{\cdot}75} \times a$$

$$= 275{,}000\, a$$

$$= 275{,}000 \text{ (semi-major axis of earth's orbit).}$$

Or, in miles,

$$d = \frac{206{,}265}{0{\cdot}75} \times 93{,}000{,}000$$

$$= 275{,}000 \times 93{,}000{,}000$$

$$= 25{,}600{,}000{,}000{,}000 \text{ miles.}$$

The magnitude of this number brings out very clearly the advantage of the astronomical unit.

Determination of the Size of an Object from its angular Dimensions, its Distance being known.—When the distance of a celestial object is known, we can, providing it is possible to measure its angular dimensions, determine its size. Thus—

$$\frac{\text{Distance of an object}}{\text{Diameter of the object}} = \frac{206{,}265}{\text{angular diameter (in seconds of arc).}}$$

The sun's angular diameter is 32′, or 1,920 seconds of arc; therefore from the above equation—

$$\frac{\text{Distance of sun}}{\text{Diameter of sun}} = \frac{206,265}{1,920},$$

Therefore,

$$\frac{93,000,000}{\text{Diameter of sun}} = \frac{206,265}{1,920},$$

Hence,

$$\text{Diameter of sun} = \frac{93,000,000 \times 1,920}{206,265}$$

$$= 866,000 \text{ miles (about).}$$

CHIEF POINTS OF CHAPTER XX.

Parallax is difference of direction produced by observations from different points of view. In geocentric parallax the two points of view are the centre of the earth and a place on the equator: in heliocentric parallax they are the two extremities of the semi-major axis of the earth's orbit. In other words, the geocentric parallax of a body is the angle subtended at that body by the equatorial radius of the earth, and the heliocentric parallax is the angle subtended at it by the semi-major axis of the earth's orbit.

Relative Distances of Planets from the Sun.—In the case of an inferior planet, that is, of Mercury or Venus, the equation is:—

$$\frac{\text{Earth's distance from Sun}}{\text{Planet's distance from Sun}} = \frac{1}{\text{Sine of greatest elongation}}$$

In the case of a superior planet, observed some time after opposition, the equation is:—

$$\frac{\text{Earth's distance from Sun}}{\text{Planet's distance from Sun}} = \frac{\text{Sine of angle sun-planet-earth}}{\text{Sine of angle sun-earth-planet}}$$

The Distance of the Sun from the earth can be determined (*a*) by means of the velocity of light and observations of eclipses of Jupiter's satellites, (*b*) by the aberration of light, (*c*) by observations of the planet Mars, or an asteroid, at an opposition (*d*) by observations during a transit of Venus.

The Parallax of a Star and therefore the distance of the star can be determined (*a*) by measuring with a transit instrument the exact place of the star upon the sky throughout a year, and applying all known corrections to the observations, (*b*) by measuring the place of the star at different times of the year with reference to other stars near it, (*c*) by taking a series of photographs of the region near the star, and measuring the change of relative position shown upon them.

Parallax, Distance and Dimensions.—Taking *d* to represent the distance of a celestial object, the following equation holds good :—

$$d = \frac{206{,}265}{\text{Parallax (in seconds of arc)}} \times \text{Base line (in miles)}$$

The angular dimensions, size, and distance are related as follows :—

$$\frac{\text{Distance of object}}{\text{Diameter of object}} = \frac{206{,}265}{\text{angular diameter (in seconds of arc)}}.$$

QUESTIONS ON CHAPTER XX.

(1) What is meant by the proper motions of the stars, and how has the distance of certain stars been ascertained?

(2) Give a method employed in the determination of the stellar parallax.

(3) Give an account of the results so far obtained on the parallaxes of the fixed stars, stating also the method employed.

(4) State the methods which have been employed to determine the distance of the earth from the sun.

(5) What methods have been applied to determine the distance of the sun from the earth?

(6) What is a transit of Venus? Explain how observations of this phenomenon help us in determining the distance of the stars.

(7) State fully one method of determining the distance of the stars.

(8) How has the distance of the Moon been determined?

(9) State the steps by which the Sun's distance is determined, using the constant of aberration and the velocity of light.

(10) How does a knowledge of the velocity of light enable us to determine the sun's distance?

(11) State exactly what is meant by (*a*) the parallax of the sun, (*b*) the parallax of a star.

(12) Describe how observations of the parallax of Mars at opposition enable the sun's parallax to be determined.

(13) State the principle of the determination of solar parallax from observations of Mars at an opposition.

(14) Describe the principle of the method used in determining the distance of the moon from the earth.

(15) How may the distance of the sun be determined by observations of a transit of Venus?

(16) Give a description of a method of determining the parallax of a star.

(17) How have the distances of certain stars been determined? State what you know concerning the distances of two or three stars.

(18) State how the distance of an object can be determined in miles when the parallax has been measured.

(19) The angular diameter of the moon is 31′ and the mean distance 238,840 miles. Determine from these data the moon's diameter in miles.

CHAPTER XXI

TERRESTRIAL MAGNETISM

Recapitulatory.—The student has in the elementary course become familiar with the conception of the earth as a magnet, and with the leading phenomena which result from this fact. He has learnt that certain natural mineral substances found in the earth's crust, notably lodestone, possess the power of attracting iron and steel, and that they are in consequence called *magnetic*. By virtue of this magnetic power pieces of lodestone arrange themselves, when suitably supported, along definite lines called magnetic meridians. Lodestone can also impart its magnetic power to pieces of steel when the latter are rubbed with it. The pieces of magnetised steel constitute artificial magnets. Such artificial magnets possess the same properties as lodestone.

He has also seen that the primary law of magnetic attraction and repulsion is, that like poles repel one another, while unlike poles attract one another.

In addition he has become acquainted with elementary ideas concerning declination (Fig. 210) and inclination (Fig. 211), subjects which will be more fully dealt with in this place.

Horizontal and Vertical Components of the Earth's Magnetism.—In the elementary lessons it was seen that a single force can be replaced by other forces which will together produce the same effect. Such a substitution is called *resolving* the force, or a *resolution* of the force. The parts into which it is resolved are spoken of as components. Any single force can have any number of components in any directions we like, but the most convenient plan generally is to resolve into two components the directions of which are at right angles to each other. After such resolution, neither component has any part in the other.

The total magnetic force of the earth acts along the direction of the dipping needle, which when arranged in the magnetic meridian, sets itself, like every magnet, along the lines of force of the magnetic field in which it is situated. But it is not customary, nor convenient, to measure the total magnetic force of the earth which acts along this line. The plan adopted is to measure that component of the total force which acts in a horizontal direction, and which is the component causing the ordinary compass needle to arrange itself along a magnetic meridian. This horizontal component of the total force is commonly referred to as the *horizontal intensity of the earth's magnetism.*

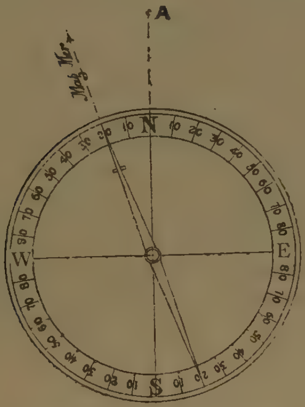

FIG. 210.—Magnetic Declination.

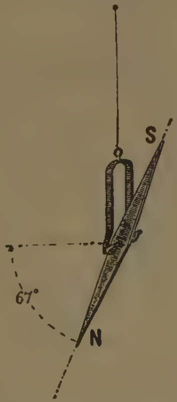

FIG. 211.—Magnetic Needle capable of moving in a Vertical Plane to show Magnetic Dip.

The relation between the horizontal and vertical components will be at once understood by referring to Fig. 212 where FT represents the total magnetic force of the earth both in magnitude and direction. This force is shown resolved in vertical and horizontal directions, and if the angle HFT is made equal to the angle of dip, then FH, and FV will represent the relative magnitudes of the horizontal and vertical components respectively.

From the First Book of Euclid (I. 47) it will be seen that the square of the total force is equal to the sum of the squares of the two components. As we have said, it is the horizontal component which is actually measured by experiment. This is conveniently done with the magnetometer, for a description of which we must refer to a work on Magnetism.[1] It is easy to calculate by a simple application of trigonometry what is the value of the total force when we know its horizontal component and the angle of dip.

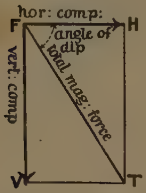

FIG. 212.—The Magnetic Elements and the Relation between them.

The average horizontal force of the earth's magnetism at London in 1896 was 1·8367 dyne-units. The angle of dip was 67° 9′.

Declination or Variation.—The magnetic poles of the earth do not coincide with its geographical poles. We shall see, as the chapter proceeds, how the former are located. Great circles round the earth, which pass through the geographical poles, are known as meridians of longitude. Similarly, circles round the earth passing through the magnetic north and south poles of the earth are called *magnetic meridians*; and it is along these, as the student has learnt, that a compass needle arranges itself. It is at once apparent that the two classes of meridians intersect one another at an angle which varies in amount from place to place on the earth's surface. This fact is illustrated by Fig. 213. It is clear that the geographical meridians, represented by continuous lines in the diagram, and the magnetic meridians shown by the dotted lines, intersect one another, as, for example, at the two stations A and B. *The angle between the geographical and magnetic meridian of any place is called the*

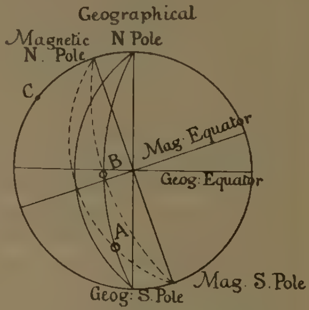

FIG. 213.—To explain Magnetic Declination or Variation.

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[1] See *Elementary Lessons in Electricity and Magnetism*, by Prof. S. P. Thompson.

declination or variation of that place, Fig. 213. Its value for any year at various places is recorded in the *Nautical Almanac.* At Greenwich Observatory in 1896 the declination was 16°·56′ West. It is interesting to note that where the magnetic and geographical meridians coincide there will be no declination as at C in the figure. The student should refer to the elementary book (p. 332) and remind himself of how to find the geographical meridian, having a compass needle and knowing the angle of declination.

Dip or Inclination.—The angle of dip[1] is measured by the help of a dipping needle.

A good form of this instrument is shown in Fig. 214. A magnetic needle, supported in a horizontal plane, is free to move vertically round a graduated circle. This circle is attached to a framework, which is carefully centred and so arranged that it can rotate about a vertical axis which passes through the centre of suspension of the needle. The centre of suspension should, moreover, be at the centre of gravity of the needle.

When measuring the angle of dip at a place with such an instrument, the framework is slowly rotated until the needle stands vertical. When this condition of things obtains we know that the plane of the needle is at right angles to the magnetic meridian. The framework is consequently rotated through 90 degrees when it is in the plane of the magnetic meridian, and the angle which the needle makes with the horizon in this latter position is an exact measure of the angle of dip at the place of observation. There are several

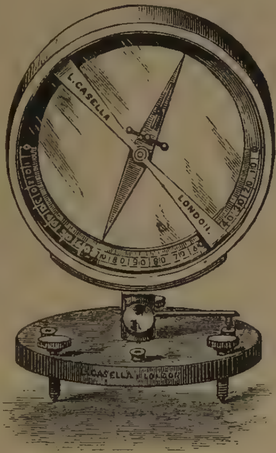

FIG. 214.—Cassella's form of Dip Circle. The instrument is arranged so that the needle sets vertically, in which case it is at right angles to the magnetic meridian. It is then turned so that it is in the plane of the meridian and indicates the dip.

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[1] The student should re-read what has been already learnt on this subject. See *Physiography for Beginners*, p. 333.

important adjustments to obviate any error in the suspension of the needle which the interested student will find explained in books on Magnetism.

The *dip circles* which are used for measuring inclination in such magnetic observatories as that of Kew are much more

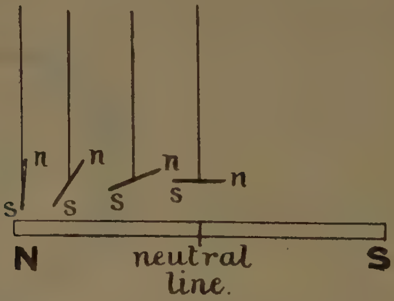

FIG. 215.—Experiment to illustrate Magnetic Dip.

elaborate and delicate instruments, but the principles of their construction and action are identical.

Behaviour of the Dipping Needle at different Places on the Earth's Surface.

EXPT. 44.—Suspend a magnetised sewing needle at its middle point by a piece of thin silk, and hold it above a bar magnet lying upon a table. Notice the behaviour of the needle above the neutral line of the magnet, above the poles and in intermediate positions. The various angles made by the needle are represented in Fig. 215.

It is seen that the needle assumes a horizontal position when above the neutral line, or magnetic equator of the magnet. When above the poles of the magnet the needle stands vertical, and in intermediate positions the needle is inclined at a greater and greater angle as the pole is approached. Moreover, over the north-seeking end of the bar magnet the south-seeking pole of the needle is below, whereas over the other end of the bar magnet the north-seeking pole of the needle is in the lowest position.

Precisely the same thing is observed in the case of the earth: in some places the dipping needle adopts a horizontal position, and a line joining in all those stations where this is so marks out the *magnetic equator of the earth*. When the needle is moved away from this equator towards the magnetic poles of the earth, the dipping needle makes a larger and larger angle with the horizon, or, what is the same thing, the angle of dip increases, until eventually the needle stands vertical or the angle of dip is a maximum. When this is so we know that the magnetic poles of the earth have been reached.

Position of the Earth's Magnetic Poles.—The magnetic poles of the earth, which are located by the vertical position of the dipping needle in their immediate neighbourhood, do not coincide with the geographical poles. The north magnetic pole, at which there must be south-seeking magnetism, because the north-seeking pole of the dipping needle is the one which dips, is situated a thousand miles away from the north geographical pole at Boothia Felix in lat. 70°5′ N., and long. 96°46′ W. Its position was discovered by Sir James Ross in 1831. The south magnetic pole has not yet been reached; but Ross found that the angle of dip, in the position lat. 76° S. and long. 168° E., was 88°37′, and it has been calculated from his observations that the south magnetic pole is located about lat. 75½° S. and long. 154° E. There is, moreover, every reason to suppose that there are two south magnetic poles.

Magnetic Maps.—The plan usually followed in recording information about the magnetic declination and inclination of any country is to mark on a map of such country the values of these two magnetic elements for different stations, and then to draw a line through the places where the value is the same. In this way by joining up the places where the amount of declination is the same we obtain lines of equal declination or *isogonic lines*. Similarly, lines through places having the same angle of dip are called lines of equal inclination, or *isoclinic lines*. A chart showing in this way the magnetic declination and the dip in the British Isles is shown in Fig. 216.

The isogonic lines for the whole earth run from the north magnetic pole towards the two south magnetic regions, which seem, as we have pointed out, to take the place of a definite south magnetic pole (Fig. 217). Their course is not regular, owing to the unequal distribution of the earth's magnetism. It is not difficult to understand the value of such a map to the mariner, who is able by its means to see whether the declination is east or west, and also whether it changes rapidly from place to place.

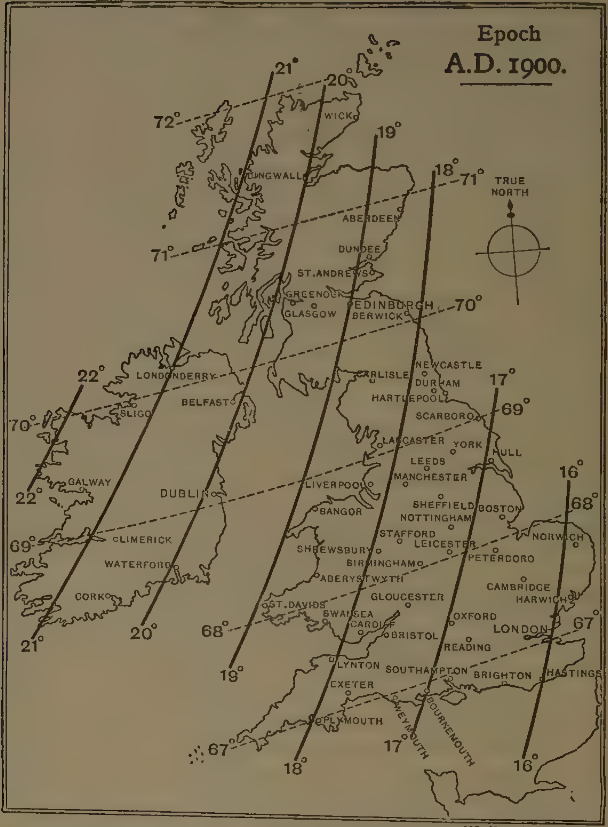

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FIG. 216.—Magnetic Chart of the British Isles, showing the lines of equal declination and those of equal magnetic dip. (From *Elementary Lessons in Electricity and Magnetism*, by Prof. S. P. Thompson.)

The isoclinic lines resemble parallels of latitude in their general arrangement, though, as would be expected from what has gone

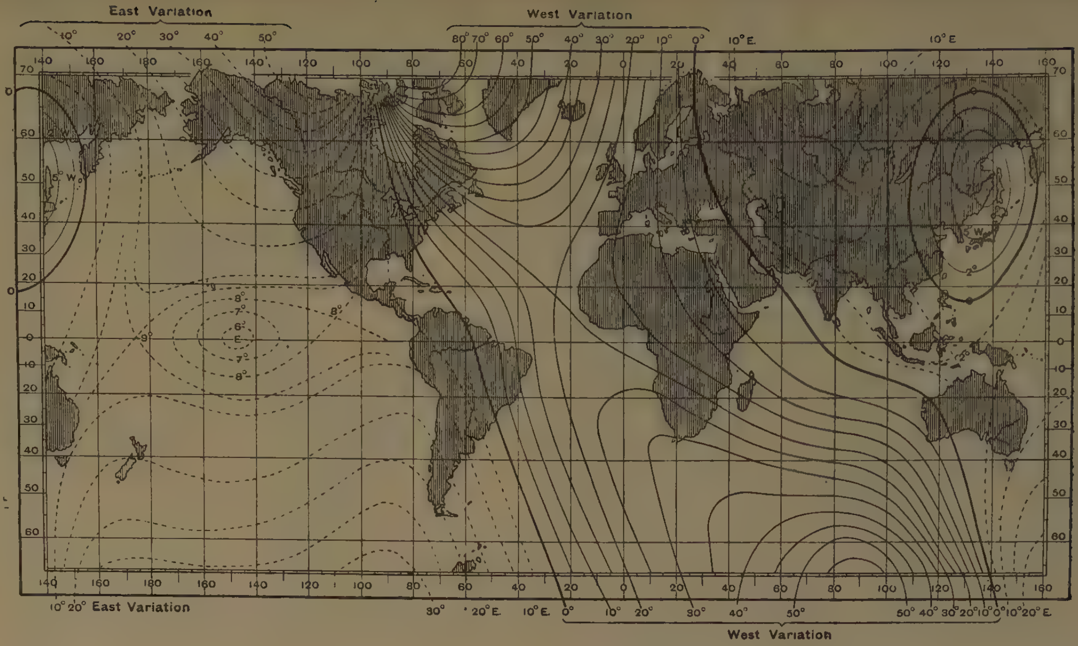

FIG. 217.—Isogoni Lines, or lines of equal Magnetic Variation.

before, they are by no means as regular (Fig. 218). The line of no dip is the magnetic equator of the earth, it is sometimes called the *aclinic line*. It is in parts fairly parallel to the geographical equator, though in maps recording the dip for recent years it is found curving to the south across S. America.

Variations of the Earth's Magnetism.—The angles of declination and dip not only vary in amount for different places but also for different times at the same place. These variations sometimes take place over very long periods, when they are spoken of as *secular*. Others happen every twelve months, while others again occur every day.

Diurnal Variations.—Careful observations with very sensitive instruments have established the fact that the direction of the compass needle does not remain strictly constant throughout the day. In Great Britain the north-seeking pole of the needle moves slightly towards the west between the hours of 7 a.m. and 2 p.m.; its westward motion then ceases and gives place to a return journey towards the east, which lasts until about 10 p.m. The hours of the night, in winter time at least, are marked by no kind of movement. During the summer months, however, there is a repetition on a smaller scale of what happens in the daytime throughout the year; for at midnight there is another movement towards the west and a return eastwards before seven in the morning.

The angle of dip is not constant throughout the day. It appears to be greatest at about 8 a.m. and least at about 3 p.m.

The needle occupies its mean position about 10 a.m. and again about 6 p.m. throughout the year. These slight movements of the needle are usually attributed to the influence of the sun and moon.

Annual Variations.—The alteration in value at different times of the year of the different magnetic elements—declination, inclination, and intensity—from month to month, seems to be connected with the earth's annual revolution round the sun. The chief facts which have been established are as follows: (i.) the total intensity (p. 455) of the earth's magnetism is in the British Islands greatest in June and least in February; (ii.) the angle of declination decreases slightly from April to July and then gradually regains its mean value throughout the other

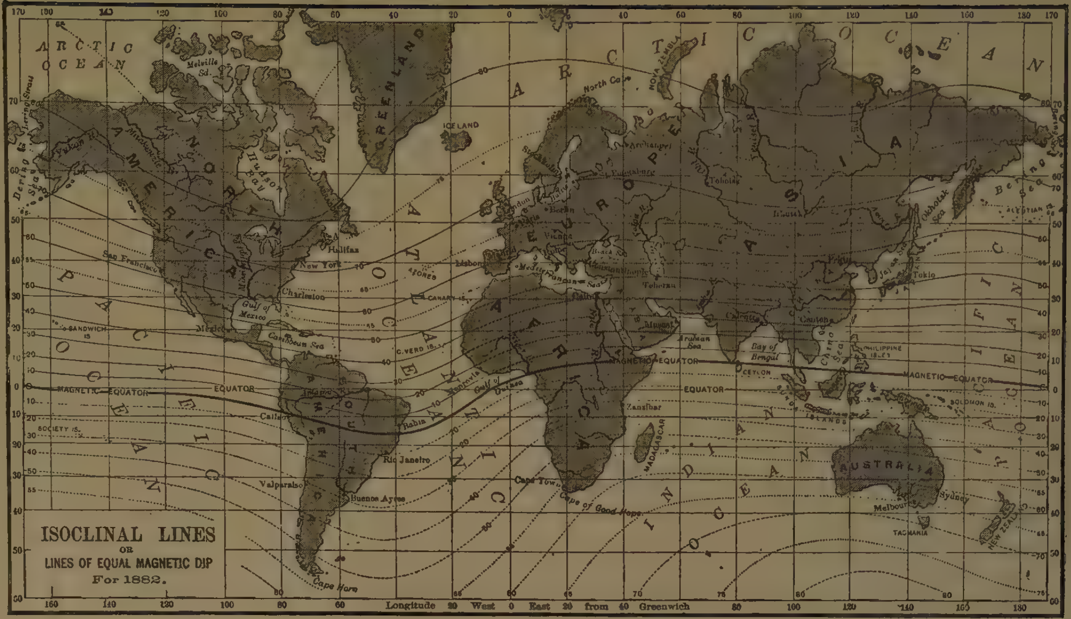

FIG. 218.—Lines of Equal Magnetic Dip. (From Appleton's *Physical Geography.*)

months; (iii.) the angle of dip is, in England, smallest during the summer months.

Secular Variations.—The variation in position of the declination and inclination needles which takes place over large periods of time can best be appreciated by examining a table showing the values of these quantities for different years.

Table of Secular Magnetic Variations at London.[1]

Year.	Declination.	Inclination.
1576	—	71° 50′
1580	11° 17′ E.	
1600	—	72° 0′
1622	6° 12	
1634	4° 0′	
1657	0° 0′	
1676	3° 0′ W.	73° 30′
1705	9° 0′	
1720	13° 0′	74° 42′ max.
1760	19° 30′	
1780	—	72° 8′
1800	24° 6′	70° 35′
1816	24° 30′ max.	
1830	24° 2′	69° 3′
1855	23° 0′	
1868	20° 33′	68° 2′
1878	19° 14′	67° 43′
1880	18° 40′	67° 40′
1890	17° 26′	67° 23′
1900	16° 16′	67° 9′

It will be at once seen that in the year 1657 the magnetic and geographical meridians coincided and there was no declination. There is no record of magnetic declination previous to 1580, when the needle pointed more to the east of true north than it has done since. This easterly declination steadily decreased until 1657, from which year until 1816 the westerly declination steadily increased, and from the last named year until the present time the amount of the westerly declination has gone on decreasing. The annual diminution is about 7′ per year, and at this rate of alteration the needle will again point due north in 1976, and the cycle of changes will have taken 320 years for its completion.

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[1] From *Elementary Lessons in Electricity and Magnetism*, by Prof. S. P. Thompson, p. 143.

The *angle of dip*, the table shows, steadily increased from 1576 to 1720, when it reached its maximum value. From that time unto the present the angle has gone on decreasing. Its value in 1897 is 67°·9′. The table further shows that the angle of dip is now decreasing in value at a lower rate than it did in the earlier centuries tabulated. The *horizontal intensity of the earth's magnetism* also gradually changes, as the following values show :—

Year.	Horizontal Magnetic Force at Greenwich in C. G. S. Units.
1888	·1820
1889	·1821
1890	·1823
1891	·1825
1892	·1826
1893	·1829
1894	·1829
1895	·1832

Connection between Aurora and Magnetic Storms.—An aurora display is generally accompanied by well-marked disturbances of compass needles. A delicately suspended compass needle is, we have just learnt, always shivering slightly out of the north and south direction, but during an aurora this movement to the east or west of the magnetic meridian is increased, and the effect is greater in proportion to the brilliancy and extent of the display.

Compass needles have been turned as much as two degrees to the east and west of the magnetic meridian at the time when bright auroras have been observed. These remarkable deflections of magnetic needles occur almost simultaneously over large portions of the earth, even where the aurora itself is not visible ; and they are termed *magnetic storms.*

It can easily be shown by experiment that a compass needle is deflected out of its true position by a current of electricity traversing a wire held above or below it ; therefore a reasonable conclusion would seem to be that the electric discharges in the upper atmosphere during an aurora affect magnetic needles in a similar way. Currents of electricity are continually passing around and through the earth, and it is probable that the directive power of a magnet is due to these currents. An aurora may thus be regarded as a visible sign of a disturbance in the general system of circulating electric currents in the atmosphere.

Magnetic storms not only accompany brilliant auroral displays, but also ebb and flow in frequency year by year, in the same period as auroræ. It has been pointed out (p. 345) that sun spots wax and wane in numbers and extent in a period of about eleven years; and observations show that the years of greatest solar activity, as evidenced by the appearance of many sun spots, are also years in which magnetic storms and auroræ are most frequent. There thus appears to be a connection between all these phenomena, though the nature of the bond has not been ascertained. The student who intends to pursue his studies of Physiography will need to go fully into the subject of the sunspot cycle and its apparent connection with terrestrial phenomena. Summing up the facts already described we may say with Prof. J. A. Fleming:[1]

"The earth may be described as a very irregularly magnetised magnet, with a pole magnetically similar to that which we call the south pole of a magnet somewhere on the south of North America, and an opposite pole somewhere in the Antarctic Ocean, but not at opposite ends of a diameter, and at some distance from the geographical poles. This great magnet is undergoing small, but fairly regular, daily and yearly magnetic changes, and also sudden, irregular, and sometimes very great magnetic changes, called disturbances or storms."

CHIEF POINTS OF CHAPTER XXI.

Recapitulatory.—The earth is a magnet. Certain substances, notably lodestone, are magnetic. Suitably suspended natural or artificial magnets arrange themselves in the magnetic meridian. The primary law of magnetic attraction and repulsion states that unlike poles attract one another, while like poles repel one another.

Magnetic Elements, or Components of Earth's Magnetism.—The total magnetic force of the earth acts along the direction of the dipping needle arranged in the magnetic meridian. For the sake of convenience it is usual to measure the component of the total force which acts in a horizontal direction. This is called the *horizontal intensity of the earth's magnetism*, and is alone instrumental in causing the compass needle to arrange itself in the magnetic needle.

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[1] *Terrestrial Magnetism*, June 1897.

Declination or Variation.—The angle between the geographical and magnetic meridian of any place is called its declination or variation. It is measured by the compass needle.

Dip or Inclination.—The angle which a magnetic needle turning about a horizontal axis makes with the horizon when the vertical plane in which it moves coincides with the magnetic meridian is known as the dip or inclination. It is measured by the *dip-circle.*

Behaviour of the Dipping Needle.—At the magnetic poles it is vertical, at the magnetic equator horizontal, in intermediate latitudes its value varies from 90° to 0°.

Position of the Earth's Magnetic Poles.—The north magnetic pole is situated at Boothia Felix (lat. 70° 5′ N.; long. 96° 46′ W.). The south magnetic has not yet been reached; there are reasons for believing there are two south magnetic poles.

Magnetic Maps are those on which the isogonic and isoclinic lines are marked.

Isogonic lines are lines joining in places having the same angle of declination.

Isoclinic lines join places which have the same angle of dip.

Variations of the Earth's Magnetism.—Such variations have been described under the following headings—*Secular*, *annual*, and *diurnal.*

Diurnal Variations.—The compass needle moves slightly towards the west between the hours of 7 a.m. and 2 p.m. The westward motion then ceases, the return journey begins and continues till 10 p.m. In winter the hours of night are hours of quiescence. In summer there is a repetition at night of what happens in day.

The angle of dip appears to be greatest at about 8 a.m., and least about 3 p.m.

Annual Variations.—The alteration in value of the magnetic elements seems to vary from month to month of the year.

The total intensity is greatest in Britain in June, and least in February.

The angle of declination decreases slightly from April to July.

The angle of dip is smallest during summer months in England.

Secular Variations.—In 1657 the angle of declination was 0°, *i.e.*, the north geographical and north magnetic poles coincided. The declination reached a westerly maximum in 1816, and is still decreasing.

The angle of dip was greatest in London in 1720, it is regularly decreasing in value every year.

QUESTIONS ON CHAPTER XXI.

(1) State what you know concerning the distribution of the earth's magnetism.

(2) What is meant by magnetic declination and inclination respectively, and how may each be observed?

(3) What observations are necessary to determine the "magnetic elements" in any locality?

(4) Name the elements of the earth's magnetism. How would you locate the positions of the magnetic poles?

(5) State what you know concerning the connection between the aurora and magnetic storms.

(6) State the magnetic elements, and how two of them are obtained.

(7) Describe how the magnetic dip is determined by means of a dip circle.

(8) Write down the declination and dip at Greenwich at the present time, and explain exactly what these two magnetic elements are.

(9) Why is it necessary for the captain of a ship to take with him charts showing the magnetic declinations in the parts of the world in which he travels?

(10) During his first voyage to America, on the evening of September 13, 1492, Columbus noticed that the magnetic needle did not point exactly to the pole star, and that as he went westward this deviation increased. How do you account for this phenomenon?

(11) What is meant by magnetic declination or variation? Is this variation the same at different places, and does it change at any one place?

(12) State what you know about the secular change of magnetic declination at London for the past two or three hundred years.

(13) Describe roughly the positions of the earth's magnetic poles, and state how (*a*) a dip needle, (*b*) a compass needle would behave if placed at a magnetic pole.

(14) If you wished to make a model to illustrate the magnetic condition of the earth, how would you proceed?

(15) Describe some evidence of a connection between auroral displays, sun-spots, and magnetic storms.

(16) Describe briefly the daily and yearly changes of magnetic declination and dip in Great Britain.

(17) How could you utilise a bar magnet and a magnetised sewing needle to illustrate the behaviour of a dipping needle at different places on the earth's surface?

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